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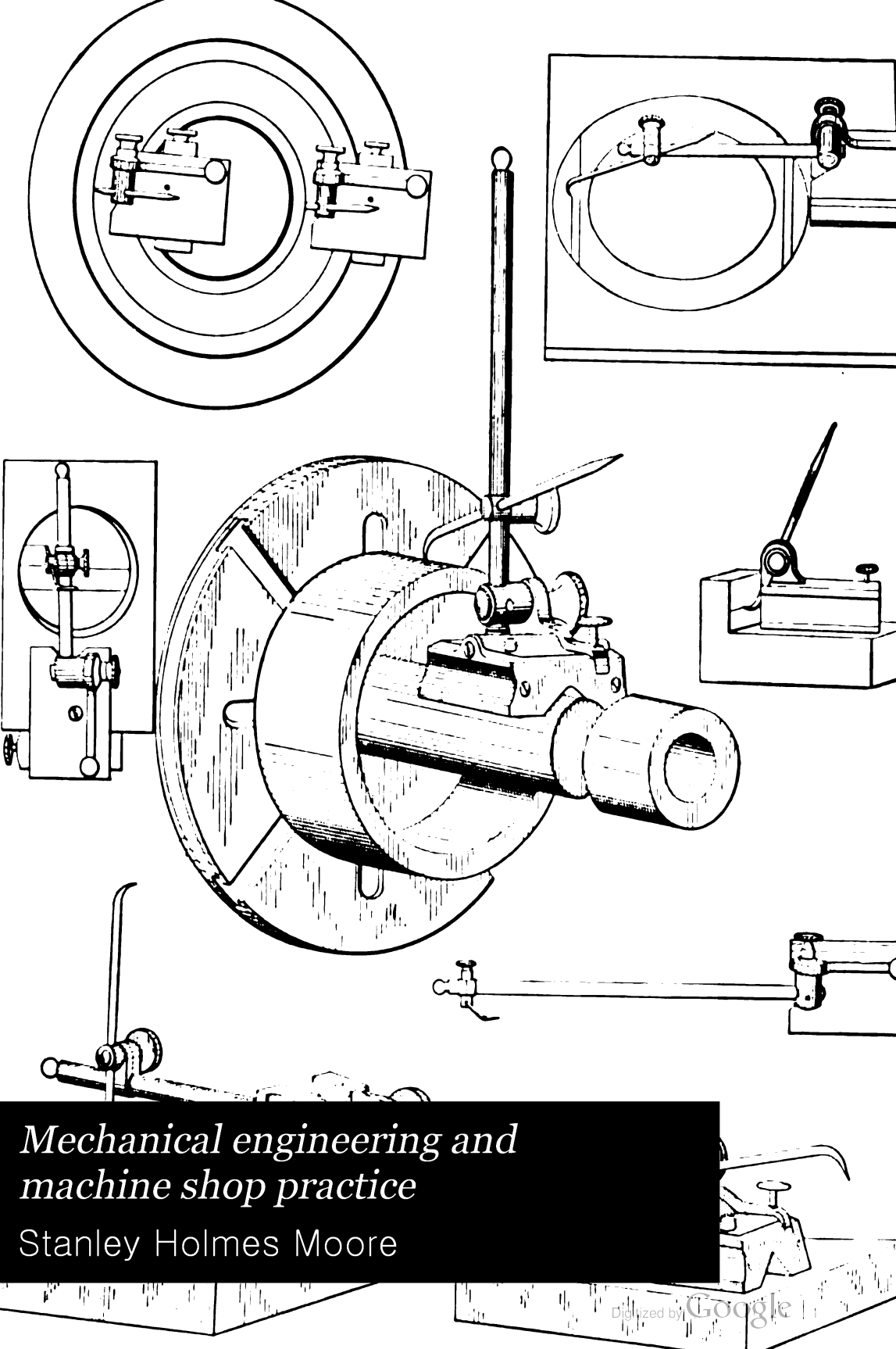

Mechanical engineering and machine shop practice

Stanley Holmes Moore

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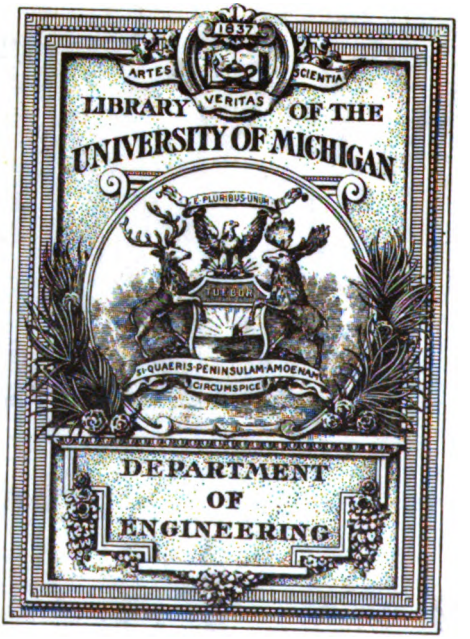

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To My Wife

WHOSE ASSISTANCE IN THE PREPARATION
OF THE MANUSCRIPT HAS BEEN INVALUABLE,
I DEDICATE THIS BOOK

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MECHANICAL ENGINEERING

AND

MACHINE SHOP PRACTICE

BY

STANLEY H. MOORE

Member or Associate Am. Soc. Mech. Engrs., Am. Inst. Elect. Engrs., Am. Asso. Adv. Sc., Am. Chem. Soc., Cen. Asso. Sc. & Math., Soc. Pro. Eng. Edu., Nat. Geog. Soc., Nat. Edu. Asso., Engineers' Club, Franklin Institute

1908

HILL PUBLISHING COMPANY

505 PEARL STREET, NEW YORK

6 BOUVERIE STREET, LONDON, E.C.

American Machinist — Power — The Engineering and Mining Journal

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The Hill Publishing Company, New York, U.S.A.

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PREFACE

1. The book deals with modern machine shop practice and its correlative mechanical engineering and is written primarily as a text for the student and apprentice.

2. The importance, and even necessity, of a limited knowledge of Materials, Processes, Mechanics, Power Generation and Transmission, Electricity and Motor Drives, to any who have to do with machine shop practice, is obvious; and for this reason, chapters containing much new matter on all these subjects have been incorporated in this work.

3. While its description of tools and processes is elementary enough and was written for students, it contains the data of original investigations and much matter of special interest to the technical man.

4. We have had and continue to have technical books from the theorist's, layman's and teacher's point of view, but the need of such works from the view-point of the student, apprentice and workman has long been apparent. By far the larger number of the paragraphs were written to answer actual questions that were asked by students and apprentices during their instruction in machine shop work.

5. Its descriptions of processes were written with the following paragraph from the Manual Training Magazine ever in mind. "If the college instructor wishes to produce a book of value to the manual training teacher, let him make a clear, scholarly description of tools and the best methods of using them, without special reference to his own particular course of study (which is pretty sure not to be acceptable to other instructors in his own grade of work, not to mention those of lower grades)."

6. The "Characteristic Operations" and the "Order of Operations" for the various machines and processes are general in character and yet specific enough for any one, able to read, to get the results desired.

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7. "If there is any one weakness common to all technical texts it is their faulty and meager index." An original and novel feature of the Table of Contents enables the reader, by means of the number after the subject, to tell at a glance the chapter, the classification and the section where the information may be found. Such a system of indexing necessitates and secures a full and logical treatment, not only of the author's specialties, but of the entire contents of the book. The illustrations are similarly indexed.

8. The information contained has gone through a process of selection and revision for a period of three years and the entire contents have been submitted to a few engineers and educators for criticism and revision.

9. Several portions have already been published in such reputable periodicals as the American Machinist, Power, Machinery, etc. One portion, Fits and Fitting, was delivered as a paper before the American Society of Mechanical Engineers; this paper was afterwards copied by a few European editors.

10. No apology is tendered for the use of half-tones, cuts, tables, etc., from the catalogs of the various manufacturers. Their function is obvious, as much material is available from no other source. The information which these catalogs often contain, the ability of the engineers who prepared them, and the skill of the artists who illustrated them, is unsurpassed.

The author desires to acknowledge his indebtedness to, and to thank all, — the publishers, manufacturers and collaborators, — for their assistance and courtesy tendered in the preparation of the work.

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CHAPTER I

INTRODUCTION AND EQUIPMENT

111. Foreword. Those of us who have had to do with the education and training of the technical student know how very difficult it is to meet satisfactorily the insistent inquiry for a comprehensive though elementary work on mechanical engineering in its relation to machine shop practice. Apprentices, workmen and students, each and all, cali for a work free alike from pedantic discussions, involved presentations, and that bugaboo of so many, complex formulas. To supply such a work was one of the author's endeavors. There are still many who object to any attempt to convey, by means of descriptions, the content of practical processes. However, it is thought that such objections are outweighed by the admitted value which recorded investigations have as time savers, and furthermore by the freedom obtained from the irksomeness of always having to begin at the beginning. In the presentations and discussions the use of *graphs* to illustrate, and in some instances to derive mathematical formulas, will, it is hoped, be most acceptable to all.

This first chapter, the bulk of which pertains particularly to, and has to do with, students and school shops, finds its justification in meeting the needs which the newly organized industrial and trades schools have created for material of this sort. The dearth of such material should make its inclusion in a work of this kind particularly acceptable to those connected with such schools. To the experienced machinist, and those whose use of the book will be chiefly for reference, much of the content of this first chapter will be found superfluous. To these the author offers the advice that they turn speedily to other pages where the subject of their inquiry may be found.

There has been an endeavor, not only to anticipate and answer such questions as arise in the mind of the student or apprentice, but also to present briefly such other knowledge of materials

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and processes as the needs of modern practice seem to demand. The work is written primarily for the student and apprentice, though it is hoped that, in this day of specialized workmen, it may be read with profit by the teacher and journeyman. We have had, and continue to have, books on engineering and shop practice from the theorist's, layman's and teacher's point of view, but the need of such a work from the view-point of the student, apprentice and workman has long been apparent.

The author has made no attempt to exhaust the knowledge of engineering in its relation to machine shops, or indeed of any one process, nor to take up in detail the process, product and each feature of every tool, but purposes to present the material of mechanical engineering in its relation to shop practice in such a manner as to obtain a maximum amount of definite knowledge and mental discipline with a minimum of words.

112. Character of Instruction. As the work of the machine shop generally comes last in a scheme of industrial education, it is taken for granted that all the experience with, and knowledge of, metals which the student possesses has been gained in the foundry and forge shop where heat was the agency by which the stubborn metal was rendered tractable and subservient. In the machine shop, however, the metals are wrought cold, being subjected to processes very similar to those employed in the working of wood, though the machines and tools are novel and peculiar and the processes altogether new. For the reason then that the work of the machine shop does come last, it is the author's purpose to simply review and emphasize the important points of the other shop processes, rather than to take up in detail the work of pattern-making, molding and forging. Those who have not had the advantage of the work of the other shops, and whose concern is mainly that of the machine shop, will find sufficient material regarding these processes as they relate to it to enable them to understand its important details.

The difficulty which always obtains in the presentation of any process by descriptions alone led to the adoption of certain schedules termed "Characteristic Operations" and "Order of Operations." The efficiency of these schedules has been demonstrated by the repeated success which has attended their use in the shop.

113. Shop Ethics. The student, confronted as he is by

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these novel conditions and processes, will find the following pertinent remarks of more than passing worth:

Learn to work in harmony with your mates, remembering that their rights and privileges are the same as your own.

Be loyal — that makes for success; be faithful — that's honest.

In the machine shop, as well as anywhere else, it is of great importance to give special attention to what is going on at the present moment. By so doing, you may prevent the spoiling of work, and perhaps serious injury to yourself.

Keep your individual tools sharp; your locker neat and clean.

Borrow no private tools. Be considerate in your use of the general tools, returning them to the tool-room as soon as possible, and in at least as good condition as when they were received.

A minimum amount of work usually accompanies a maximum amount of talk.

Courtesy demands that you refrain from passing remarks concerning the troubles of others — you may soon have some of your own.

When curious or in doubt in reference to your work or machine, consult the teacher, assistant or foreman — that's what they are hired for.

Be thoughtful and deliberate. Do your thinking beforehand; the afterthoughts of too many people find expression in terms more forceful than elegant.

114. Carefulness in the Shop. The following concise and pithy paragraphs relative to the care of self and the care of machines are taken from Brown & Sharpe's excellent little work for apprenticed machinists:

"If a machine is set wrong it may spoil valuable work.

"The effect of some mistakes may not always be immediate and severe.

"A pupil may go to a recitation without having studied his lesson, and yet be able to answer the questions put by the teacher. In a machine shop, however, if a workman makes a mistake in running a machine, the machine never excuses him. If he gets in the way of a machine, he is always punished, and often with extreme severity. A man stopped a planer by half shifting the reversing belts, without stopping the countershaft overhead. He bent over to look into the place where he had just been

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planing; his leg pushed the operating lever, the planer started, and the tool ploughed deep through his skull."

115. Care of Self. *"Want of care does more damage than want of knowledge"* [the italics are mine]; hence, care and knowledge should be well commingled. It is easier to form a habit than to break one off; therefore we should strive to form correct habits.

"Before beginning to learn machine making we should learn that it is dangerous to lean against a machine that is running, and that it is important to keep a proper distance from any mechanism that is in motion, or is likely to be set in motion. It is sometimes convenient to place one's hand upon a moving piece, but before doing so one should know the direction of the motion, and the place touched should not be the teeth of a gear or the teeth of a cutter. If one touches a piece supposed to be moving south when in reality it is moving north, one's hand may be seriously injured.

"In touching a belt that is running, the hand should be kept straight, and should touch the belt only upon its edge; if the fingers are bent they may be caught between the belt and pulley.

"Never put your fingers in the way of a machine for fun; in short, never play with a machine at all, for it will not stand a joke.

"It is dangerous to set a lathe tool when the work is running, and still more dangerous to set a planer tool."

116. Care of Machine. "Having given our young machine maker some points for his own safety, we should like to give him a few for the safety of the machines themselves. While the machine acts according to a blind and unconscious necessity, apparently with utter fierceness and cruelty, yet it can be very easily injured. Do not allow a tool to run by the work so far as to chuck or bore a lathe spindle. Do not score the platen of a planer. Do not make holes in the table of a drilling machine. Do not gouge the footstock or vise of a milling machine. Do not lay a file or any other tool upon the ways of a lathe; they should be guarded with the greatest care. Do not cut into a lathe arbor.

"The running parts of every machine should be oiled at least once a day, and perhaps oftener. Slides and other exposed bearings should be wiped clean before oiling. If you take a machine that some one else has been running, do not trust that it has been oiled the same day, oil it yourself. If a machine is

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not properly oiled, it makes a damaging report, it roughs up and stops, often requiring hours to repair before it will run again.

"After a machine has thus been stopped, you need not tell that it has been properly oiled, because nobody will believe you. The evidence of the machine deals only with facts and not with fictions. Even though an abundance of oil has been put into the oil-holes, the bearings may not have been properly oiled, because the oilways are plugged up with dirt. It is a bad sign to have the oil remain in the holes without sinking at all, when the machine is running. Every oil-hole should be vented so that when oil is forced into one place it can be seen oozing from another. If an oil-hole is not vented the oil may rest on a cushion of air which tends to lift the oil out. If the vent is plugged up it is safer to take the bearings apart and clean the oil-ways, but sometimes a vent can be cleaned by forcing in naphtha or benzine. If you have been so unfortunate as to have a bearing roughed, the first thing to do is to force in naphtha or benzine; the next thing is to take the bearing apart and have the rough places carefully dressed. Like many other troubles that have come once, the roughing of a bearing is likely to come again.

"It can hardly be expected that one can follow the calling of a machinist without soiling one's hands, yet there are grades in grime, and some grades are more offensive than others. From a mechanic's point of view, one machine may be dirty, while another is clean. There are work-shops that are kept in a more healthful condition than some dwelling houses.

117. Tools and Work. "Some workmen arrange their tools so that they can be easily reached and do not let files destroy one another by throwing them together. The use of a monkey-wrench for a hammer indicates poor taste; and to jam a piece of finished work in a vise or under a set-screw proves that a man lacks in mechanical ability; whatever else he succeeds in, it is very unlikely that he can ever become a good workman. Any man to whom a bad job is not a lasting mortification shows himself deficient in self-respect. A long job may soon be forgotten, a bad one never."

Instructions as to what is wanted, or how the work is to be done, may be had verbally from the teacher or foreman, or gathered from the mechanical drawing. The student or apprentice should give special attention to these instructions and never

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commence work until he understands thoroughly just what is wanted. It is very important that he form the habit of measuring such stock and castings as are presented to him for machining to determine, prior to any work, whether or not the piece will finish to dimension.

Shop Equipment and Regulation

121. Machine Tool Equipment for Shop or Laboratory. An excellent laboratory equipment for the teaching of machine shop practice, suitable for a class of twenty students, would consist of the following tools: —

Ten 14″ First-class Engine Lathes, with Chucks and Change Gears.

Two 20″ First-class Engine Lathes, Hendey-Norton Type, with Chucks and Taper Attachment.

One Flat Turret Lathe.

One 36″ Boring Mill.

One Small Radial Drill or 26″ Medium Upright Drill.

One 28″ x 7″ Planer.

One Speed or Sensitive Friction Drill.

One 16″ Shaper.

One Universal Milling Machine.

One Universal Grinding Machine.

One Dry Emery Grinder.

One Wet Emery Grinder.

One Drill Grinder.

Two 10″ Speed Lathes.

One Gas Forge and Air Compressor.

One Power Hack or Cold Saw.

One Small Power Press and Dies.

Eight 4″ or 4½″ Heavy Machinist's Vises, attached to Suitable Work-benches.

Ten Sets Vise Tools, with Suitable Lockers or Cupboards.

Ten Sets Lathe Tools, with Suitable Lockers or Cupboards.

In addition to the above equipment it is necessary to have the tool-room stocked with such general small and measuring tools and materials as are mentioned throughout the subsequent pages of this book.

122. The Tool-room. The tool-room and its successful management is one of the most important problems which pre-

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sents itself to him who has charge of the shop. The tool-room is the depository for all the general and special small tools and for such small supplies as are easily handled. The tool-keeper should be solely responsible for all the tools and supplies under his charge, and should exercise as much care in noting the condition of the returned tools, as he does in promptly complying with the reasonable requests of his mates.

The two common systems by means of which a workman may draw tools from the tool-room are the Check and Record Systems.

123. The Check System. This system employs the use of brass checks, several of which, stamped with the workman's number, are issued or presented to him for his personal use. When he desires a tool from the tool-room, he makes his request and presents a check; this check the tool-keeper places in the position of the tool which he gives to the workman. When the tool is returned in good condition it is put into its place and the check returned to the owner.

124. The Record System. On pages 8, 9 and 10, are given fac-similes of tool and time records; their use is easily gathered from a reading, rendering any explanation superfluous.

125. Tool-room Rules for School Shops. 1. The tool-keeper is required to examine and make a daily report of all small tools, stating their present condition, and reporting all missing or broken articles.

2. The tool-keeper is not allowed to leave the tool-room without permission from the teacher.

3. The tool-room must always be neat and clean, the tool-keeper taking care to see that each tool is in its proper place before leaving to wash.

4. Credit will be given for tool-room work, provided the student has successfully performed the same: *i.e.* has kept the tool-room neat, clean and in order at all times.

5. The student may chip, file and scrape a surface plate when not engaged in the legitimate tool-room work.

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TOOL AND TIME RECORD

MACHINE SHOP

MANUAL TRAINING HIGH SCHOOL, - KANSAS CITY, MO.

Student's Name.....
Date..... Period.....
Time spent at work on Exercise No.....
Kind of work done.....
Vise or Machine Tool used during period.....
.....
.....

Put a Cross opposite Tools required from Tool Room

LATHE SET			VISE SET		
Cross	Drawer No.....	Check	Cross	Drawer No.....	Check
....	Calipers, 3-in., Outs. Spg.	....	....	Calipers, 6-in., Outs.....	....
....	" 4-in., Ins.....	....	....	Center Punch	....
....	Center Gage	....	....	Chalk and Box.....	....
....	" Punch	....	....	Dividers, 3-in. Spg.....	....
....	Chalk and Box.....	....	....	File Cleaner.....	....
....	File, 12-in. Mill B. Sg. Cut	....	....	" Handle.....	....
....	" Cleaner.....	....	....	" 12-in. Flat B. Dbl. Cut	....
....	" Handle.....	....	....	" 12-in. Mill B. Sing. "	....
....	Lathe Tool, Armst'g No. 1	....	....	" 12-in. Half Rd. B. Dbl. "	....
....	" " Thread'g Ins.	....	....	Hammer, 24 oz.....	....
....	" " Left Side.....	....	....	Scriber, 8-in.....	....
....	" " Bent "	....	....	Slip Stone.....	....
....	Piece Copper.....	....	....	Steel Rule	....
....	Slip Stone.....	....	....	Try Square	....
....	Steel Rule.....	....	....	" " Blade, 45-60 ..	....
....	Tool Pan.....	....	....	Tool Pan	....
	INDIVIDUAL SET	....	....	.....	....
		....	....	.....	....
....	Cold Chisel.....	....	....	.....	....
....	Cape Chisel	....	....	.....	....
....	Diamond P't Lathe Tool..	....	....	.....	....
....	Round Nose Lathe Tool..	....	....	.....	....
....	Right Side Lathe Tool....	....	....	.....	....
....	Parting Lathe Tool.....	....	....	.....	....
....	Boring Lathe Tool.....	....	....	.....	....
....	Threading Lathe Tool.....	....	....	.....	....

Remarks: Tool Keeper must check all tools returned in good order and report all broken ones on this record.

.....*Tool Keeper.*

This record must be handed to the teacher before you leave the shop.

FIG. 124*a*. — A School Tool and Time Record.

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SHOP RULES

1. No student is permitted to work in the shop without overalls, jacket, and cap, which must be in good condition.

2. Students must have on shop clothes and be ready to begin work when the tardy bell rings.

3. Students are cautioned against using tools before the use and operations of same have been explained to them. Each tool, bench and machine should be carefully examined, and machines turned over by hand, before being used, and any defect, damage or loss reported at once. The last user will then be held responsible.

4. Each student is held responsible for the equipment of which he has charge. All breakage or loss must be made good.

5. The shop hours must be devoted to shop work. Loud talking, collecting in groups and sitting on benches or machines is forbidden. Deportment and neatness are important factors in the determination of a student's standing.

6. With the exception of grinding machines, no machine is to be used without permission.

7. Special permission must be obtained from the teacher before work, other than that assigned by him, may be undertaken.

8. As soon as an exercise is finished it should be stamped with the student's initials and locker number and handed to the teacher. Credit will be given imediately for properly stamped and finished work. Lost exercises must be repeated.

9. Tool and time records are provided on which each student is to record the actual time spent on each piece of work, the kind of work, and machine tools used during the period.

10. Students are not to leave the shop without permission.

11. When through work, the machine, vise, or bench must be cleaned with brush and waste. Before leaving the shop to wash, all small tools must be returned and checked.

12. A student's report represents not only the quality of the finished work, but also the time he has spent upon it and his attitude toward the work; *i.e.* his disposition to attend to business and to profit by given instructions. Repeated disorder, inattention, or disregard of shop rules will necesarily result in trouble for the student.

FIG. 124*b*. — Reverse side of Fig. 124*a*.

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EXERCISE AND TIME RECORD

MECHANIC ARTS DEPT. McKINLEY HIGH SCHOOL

Name.....Periods.....
Commenced.....Finished.....
No. pcs. stock used.....Kind of work done.....
Total time.....on Exercise No.....

Date	Time	Equipment Used	Received from Tool-room

Dimensions	5
Finish	2
Time	1
Tools	1
Deportment	1
Grade on Exercise	

Tool-keeper must check all tools returned in good order and report all broken ones at once.

This record must be handed to the teacher by the student before he leaves the shop.

Tool-keeper.....
Approved.....

FIG. 124c. — A School Exercise and Time Record.

NOTE: The above record is used in all shops — Joinery, Forgey, etc.

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CHAPTER II

MATERIALS

Iron, Metallurgy

211. Ores and Their Reduction. This most important of metals is also one of the most abundant. The principal ores from which iron is obtained are: magnetite, Fe_3O_4, hematite, Fe_2O_3, limonite, $2\,Fe_2O_3 + 3H_2O$ and siderite, $FeCO_3$. What is commonly known as pig iron is the result obtained from smelting iron ore. Ore containing less than 50% of iron is seldom smelted in the furnaces of the United States. The ore is put into the blast furnace with a fuel and a flux, — a flux being that material which, when melted with the ore, promotes fusion by combining with the earthy matter and by-products, allowing the metal to separate. The fuel is generally coke, coal or charcoal, and the flux limestone. The entire mass is melted under the forced draft, and when a sufficient quantity of the ore is reduced to metallic iron at the bottom of the furnace, the furnace is tapped, and the iron allowed to run into ditches, from which it flows into side-pockets; or, as in more recent practice, it is drawn directly into molds. In the first instance it is necessary to break the pieces apart; this is done just after the iron "sets." This product is the commercial pig iron.

212. Graphical Illustration of the Metallurgy of Iron. The following chart (Fig. 212) was prepared after a thorough investigation of the various metallurgical processes, and it is believed to be a more complete and convenient presentation of the subject than any yet published.

The diagram illustrates graphically the metallurgy of iron, tracing its journey from the mine to the market; it affords a means of tracing out the various processes and their relations, and indicates roughly the kind of iron or steel produced by each process.

From a survey of the chart we see that the refractory ores,

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and those containing volatile substances, pass first to the Roasting or Calcining Furnace; they then go to the Blast Furnace where the ore is changed into the commercial pig irons. Again the ore

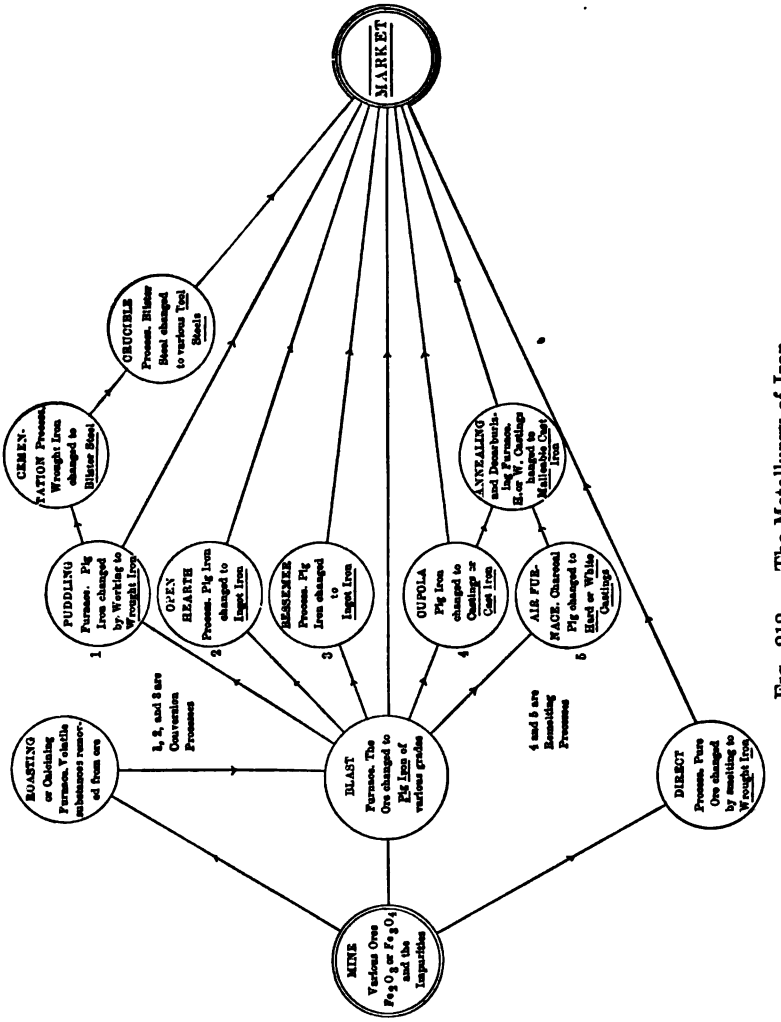
MARKET
CRUCIBLE Process. Blister Steel changed to various Tool Steels
CEMENTATION Process. Wrought Iron changed to Blister Steel
ANNEALING and Decarburising Furnaces. Iron or W. Castings changed to Malleable Cast Iron
PUDDLING Furnace. Pig Iron changed by Working to Wrought Iron
1
OPEN HEARTH Process. Pig Iron changed to Ingot Iron
2
BESSEMER Process. Pig Iron changed to Ingot Iron
3
CUPOLA Pig Iron changed to Castings or Cast Iron
4
AIR FURNACE. Charcoal Pig changed to Hard or White Castings
5
ROASTING or Calcining Furnace. Volatile substances removed from ore
1, 2, and 3 are Conversion Processes
BLAST Furnace. The Ore changed to Pig Iron of various grades
4 and 5 are Remelting Processes
DIRECT Process. Pure Ore changed by melting to Wrought Iron
MINE Various Ores Fe_2O_3 or Fe_3O_4 and the Impurities

FIG. 212. — The Metallurgy of Iron.

may go directly from the mine to the Blast Furnace, or in the case of some grades of pure ore it is changed, by the direct process, into wrought iron, finding its way to the market as such. The product of the Blast Furnace is put on the market as the com-

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mercial pig irons; these may, by passing through some one of the conversion processes, be made into iron or steel; or they may, by way of either of the remelting processes, reach the market as cast iron or malleable cast iron. If treated in the Puddling Furnace the pig iron is changed to marketable wrought iron. Wrought iron when treated by the Cementation Process becomes blister steel. This blister steel is passed through the Crucible Process and the product reaches the market as tool steel. If pig iron is treated by the Open Hearth process it is changed to what is known as ingot iron, in which form it goes to the market. Treated by the Bessemer Process pig iron is also changed into ingot iron.

If, however, castings are wanted, the pig iron is remelted, mixed with scrap, etc., in the Cupola and the product is cast iron. When "Charcoal Pig" or any pig iron free from sulphur is treated in the Air Furnace and cast, hard or white castings result; these brittle castings now pass to the Annealing and Decarburizing Furnace where they are changed into malleable cast iron. Cupola castings are sometimes treated in the Annealing and Decarburizing Furnace, in which case they become malleable cast iron.

213. Metallurgical Notes. Cast iron usually contains over 3% of carbon; cast steel anywhere from .06% to 1.6%, according to the purpose for which it is used; wrought iron from .02% to .10%. The quality of hardening and tempering which formerly distinguished steel from wrought iron is now no longer the dividing line between them, since soft steels are now produced, which by the ordinary blacksmith's tests will not harden. All products of the crucible, Bessemer and open-hearth processes are now commercially known as steel.

Pure iron is extremely infusible, its melting point being above 3000° F. It is malleable, tough and ductile and as far as can be determined from the strength of steel, it has an extreme tensile strength between 38,000 and 39,000 pounds per square inch. By different processes cast iron and wrought iron are produced directly from pig iron; the cast iron being produced by melting the pig in a cupola and casting in molds. In structure it is hard, crystalline and brittle.

The other properties which we note in cast iron and steel are due principally to the presence of carbon, the most of which

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is absorbed from the fuel in the process of reduction. With the addition of carbon the fusibility of iron increases, cast iron fusing at from 2000° F. to 2500° F.; the average temperature at which steel fuses being about 2550° F.

The addition of carbon renders iron and steel hard and brittle. In cast iron only a portion of the carbon is chemically combined with the iron, some of it existing as free or graphitic carbon. This constitutes the chief structural difference between cast iron and steel. Cast iron is then a chemical combination of iron and carbon, generally containing some other elements, as silicon, phosphorus, sulphur and manganese, which give to it certain peculiar characteristics, according as they vary in quantity.

214. Influence of Carbon, Manganese and Phosphorus. *Carbon* is the element above all others which steel makers employ, where price is a consideration, in the production of steels of required physical properties. In general, it may be stated that a given content of carbon will confer a greater hardness and strength with less accompanying brittleness than any other element. Certain exceptions, however, must be made in the cases of the hard steels containing chromium, manganese and tungsten. It is well known that every increment of carbon decreases slightly and regularly the ductility of iron, and increases its hardness, brittleness under shock, and its liability to crack and check under conditions of sudden heating and cooling. The combined carbon content is always small, seldom exceeding one and one half per cent.; yet the effect of even small increments is strikingly illustrated by the fact that an increase of $\frac{1}{100}$ of one per cent. will give an increase in tensile strength of about 1000 pounds per square inch.

If a piece of red-hot steel (iron plus combined carbon) be suddenly quenched in cold water, a compound of extreme hardness results; the carbon and iron in the metal combining in some peculiar way which is not thoroughly understood. A carbon content of 1% gives about the limit of useful hardness, the higher carbons producing steels which increase so rapidly in brittleness that their usefulness is all but destroyed.

The following conclusions are taken in the main from the recorded investigations of H. H. Campbell, and are given in his book, "The Manufacture and Properties of Iron and Steel," as

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the result of extended experience covering several hundred heats of both acid and basic open-hearth steel.

Manganese. Probably the most important function which manganese serves is that of giving ductility while the steel is hot so that the piece may be rolled and finished without tearing. Above .60%, while adding to the tensile strength, it does not materially decrease the ductility; however, though not proven, it seems slightly to increase its liability to break under shock. An increase of $\frac{1}{100}$ of one per cent. (.01%) of manganese has very little effect upon acid steel unless the content exceeds .60%, but it raises the tensile strength of basic steel about 85 pounds per square inch.

Phosphorus. This element has little effect upon the hot properties of steel, but produces what is commonly termed "cold shortness," a term used to designate great brittleness in the finished steel. Phosphorus always exists as an impurity, and of all the elements commonly found in steel, it stands pre-eminent as the most undesirable. Its tendency to produce coarse crystallization, and the consequent reduction in the temperature at which it is safe to heat steel, make it highly objectionable in the rolling-mill.

The phosphorus content of ordinary steels is always limited to .1% while in special steels much lower limits are specified. An increase of $\frac{1}{100}$ of one per cent. (.01) % of phosphorus raises the tensile strength of acid steel about 890 pounds per square inch and of basic steel about 1050 pounds per square inch.

Carbon — Manganese — Phosphorus. The following formulae will give the ultimate tensile strength of ordinary open-hearth steels in pounds per square inch, the carbon, manganese and phosphorus being expressed in units of .001% and a value being assigned to R in accordance with the conditions of rolling and the thickness of the piece.

The formula for acid steel is:

38600 + 121 Carbon + 89 Phosphorus + R = Ultimate Strength.

The formula for basic steel is:

37430 + 95 Carbon + 8.5 Manganese + 105 Phosphorus + R = Ultimate Strength.

The metals from which these data were derived were ordinary

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structural steels ranging from .02% to .35% carbon, and it is unlikely that the formulas are applicable to higher steels or to special alloys. In the case of acid steels an increase in manganese above .60% will raise the tensile strength above the amount given by the formula, the increment being quite marked when a content of .80% is exceeded.

In steel containing from .30% to .50% of carbon, the value of the metalloids is fully as great as with lower steels, while the presence of silicon in such metal in proportions greater than .15% seems to enhance the strengthening effect of carbon. In steels containing less than .25% of carbon, the effect of small proportions of silicon upon the ultimate strength is inappreciable.

215. Influence of Chromium and Nickel. *Chromium* is employed to give an extreme hardness to steel, the peculiar characteristic being that no quenching or tempering is required. The addition of chromium up to 5% increases the tensile strength of steel and its resistance to shocks, but above this percentage the tensile strength is lowered.

Nickel imparts to steel a high elastic limit and great toughness under shock, and in combination with carbon prevents what is known as "sudden rupture," though its influence is not always uniform. Nickel is used to obtain a steel that will withstand the heavy shock and torsional tests that are required of armor plate and special forgings.

216. Influence of Silicon and Sulphur. *Silicon* cannot be classed among the highly injurious elements like phosphorus and sulphur, for it seems to exert but little influence on the mechanical properties of steel even when the content is as great as 5%. All attempts at welding silicon steel are unsatisfactory except in steel castings where up to .4% of silicon in the mixture is permissible; anything but a trace of silicon is seldom found. Silicon has a tendency to make cast steel creamy and sluggish, though it will run better in the small passages of a mold than ordinary steels; which latter are rendered slow by the sputtering and consequent impediment to the passages which occurs when the ordinary steel is cast.

Sulphur is an injurious content and exists as an impurity, having just the opposite effect from that of manganese. It not only injures the rolling qualities of steel, producing what is known as "red-shortness," causing it to crack and tear, but it

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lessens its capacity to weld. In its effect upon the cold properties of steel, sulphur seems to exert no appreciable influence within the limits of the common content, which varies from .02% to .10%.

217. Influence of Tungsten, Molybdenum and Vanadium. *Tungsten.* The effect of tungsten, in conjunction with over 1.5% of manganese in tool steel, gives extreme hardness and brittleness and the peculiar characteristic, like that of chromium, of requiring no quenching or tempering, producing a steel almost as hard when cooled slowly in air, from a forging heat, as carbon steel when cooled in water. It is the chief element in the production of the self-hardening tool steels; its valuable properties having been discovered by Robert Mushet about 1865. Tungsten is not the true hardener but plays the important part of the mordant by means of which the alloy produced is enabled to contain a larger combined carbon content.

Molybdenum was substituted in the Taylor-White process for the tungsten in the production of modern high-speed tools, for the reason that one part of molybdenum effects approximately the result of two parts of tungsten; that is, it combines with the chromium in the same manner as tungsten and produces the new quality of "red hardness," which is the main feature of the Taylor-White discovery. However, it was discovered, that, while molybdenum produced the self-hardening properties and brittleness of tungsten it was not as satisfactory an element, because the effect was irregular; that is, tools of the same chemical composition, apparently treated alike, gave large variations in cutting speed and possessed a peculiar brittleness and tendency to fire crack. For these reasons molybdenum was discarded.

Vanadium like carbon, is capable of producing great changes in the physical properties of steel by the addition of very small percentages. It has a tendency to cause brittleness, but vanadium steels excel all others in their ability to resist dynamic stresses. Mr. Taylor states that their experiments indicate the probability that the good effects of vanadium in high-speed steels are derived from its chemical property as a cleanser of the steel during the operation of melting, rather than as a very valuable property of the steel after it is melted. In its action as a cleanser it probably unites with some of the obscure oxides and carries them off in the slag.

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Vanadium should not be substituted for chromium in tool steels, but should be added to the mixture in melting in quantities of from .15% to .35%; these are as effective as greater quantities in the mixture. The best high-speed steel produced contains .29% of vanadium.

218. Influence of Aluminum, Cobalt, Tin and Titanium. *Aluminum.* Mr. Campbell makes the following remarks concerning aluminum: "It is hardly necessary to discuss at length the effect of aluminum upon steel, for although it is often used to quiet the metal, it unites with the oxygen of the bath and passes into the slag." Sometimes a very small percentage remains in the steel castings.

The addition of .5% of aluminum increases the tensile strength between 3000 and 8000 pounds, raises the elastic limit in about the same proportion and injures very materially the elongation and contraction of area. The addition of another .5% does not have much effect on the ultimate strength or elastic limit, but still further decreases the ductility of the metal and at from 2% to 3% it causes great brittleness. The effect upon the strength and ductility is more marked in low than in high steels. The addition of .5% to 1% to cast iron increases fluidity and makes casting possible with the whiter irons. When melting, the addition of a proper amount of aluminum will "kill" the most "fiery" of steels and allow it when "dead" to pour like the dead melted silicon steels.

Cobalt, Tin and Titanium. In a paper before the French Society of Civil Engineers, M. Guillet, 1907, brings out the following points: Cobalt, Tin and Titanium in steels enter into solution in the iron and the carbon exists therein — at least within the range of the experiments made — in the shape of iron carbide. The mechanical properties of these steels do not seem to promise any industrial application thereof. They do show very clearly, however, the marked difference between tin, titanium and silicon steels on the one hand and nickel and cobalt on the other.

219. Table of Physical Properties. The graph (Fig. 219*a*) though of more than passing interest here, is self-explanatory. In the table of physical properties, on page 20 (Fig. 219*b*) compiled from recent authorities, average values are given. The atomic weight of iron is 56.

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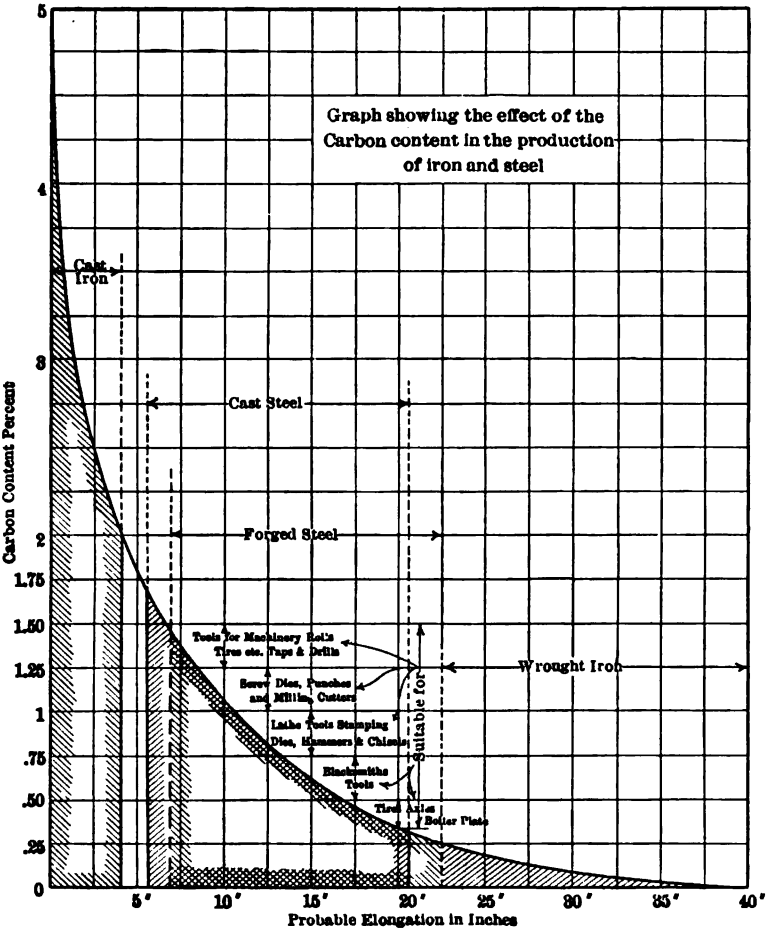

FIG. 219a. — Physical Effect of the Carbon Content.

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	Specific Gravity Mean Values	Specific Heat	Temperatures of Fusion. Fahr.	Weight of a Cubic Inch	Coefficient of Linear Expansion	Conductivity for Heat. Silver at 100	Conductivity for Electricity. Silver at 100	Modulus of Elasticity	Ultimate Strength in Lbs. per Sq. Inch.	
									Tension	Compression
Cast Iron	7.218	.1298	2300	.2604	.00000617	35.9	12 to 14.8	17,000,000	20,500	95,000
Wrought Iron	7.70	.1138	2912	.2779	.00000686	43.6	Swedish 16	26,000,000	50,000	50,000
Steel	7.854	.1170	2550	.2834	.00000599 to .00000702	39.7		30,000,000	70,000	70,000

FIG. 219*b* — Physical Properties of Iron and Steel.

PIG IRON

221. Classification of Commercial Pig Irons. The classification of pig iron by fracture, on account of its unreliability, is about obsolete, and makers of pig iron rely solely on the chemical analysis. The modern classification, therefore, states the maximum or minimum quantities of the elements which a given grade of pig shall contain. Accordingly we have:

222. Bessemer. Bessemer iron must not exceed 2.5% of silicon, 1% of phosphorus, .05% of sulphur, while the manganese may vary from .3% to 1%. Bessemer iron is used chiefly in the manufacture of steel ingots and for such products as are obtained from them.

223. Foundry. Foundry iron, though similar to Bessemer iron, may contain from 2% to 4% of silicon, and phosphorus up to 1%, while the .05% of sulphur and the .3% to 1% of manganese remain the same. Foundry iron, on account of its flowing well, may be used for intricate castings.

224. Charcoal. Charcoal iron is so called because it is made with charcoal, to eliminate the sulphur found in other fuels, and for this reason it is very low in sulphur. It should contain less than 2% of silicon, not over 1% of phosphorus, less than .01% of sulphur and not more than 1% of manganese.

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225. Basic. Basic iron should not contain over 1% of silicon, although the phosphorus content may vary from .3% up to as high as 1%; it should rarely exceed .4%. Basic iron should never possess more than .05% of sulphur and 1% of manganese.

226. Ferro-Silicon. Ferro-silicon iron is used chiefly as a softener in a mixture of hard grades of pig iron. It generally contains from 6% to 16% of silicon; from .5% to 1.5% of phosphorus, sulphur from .01% to .05% and manganese up to 3%.

227. Gray Forge. Gray forge iron is the poorest and cheapest iron on the market. It is used chiefly for the manufacture of water pipes and the production of wrought iron. It generally contains less than 1% of silicon; is high both in phosphorus and manganese, and often as high as .1% in sulphur.

Cast Iron

231. Classification and Analyses of Standard Cast Irons. The following classification and analyses of cast iron is compiled from data submitted by the committee appointed by the American Foundrymen's Association to investigate and standardize the product:

Class of Iron	Iron	Graphitic Carbon	Combined Carbon	Total Carbon	Silicon	Phosphorus	Sulphur	Manganese	Average Strength in Lbs. Per Sq. In.	Average Deflection in Inches
Chill Roll	95.75	2.45	.061	3.06	.84	.547	.071	.285	4487	.090
Gun Metal	95.12	2.47	.76	3.23	.73	.453	.059	.408	4264	.110
Car Wheel	94.99	2.36	1.07	3.43	.78	.364	.132	.306	3610	.070
General Machinery	94.10	3.31	.58	3.89	1.30	.433	.053	.224	3111	.072
Stove Plate	92.47	4.00	.19	4.99	2.47	.508	.094	.265	2530	.078
Bessemer	93.75	3.77	.49	4.22	1.52	.083	.059	.326	2430	.100

232. Malleable Cast Iron. The description submitted by the "nomenclature committee" at the Brussels Congress of the International Association for Testing Materials, 1906, is as follows: "Iron which when first made is cast in the condition of cast iron, and is made malleable by subsequent treatment without

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fusion . . . is not truly a variety of cast iron but rather forms an independent species of iron because it lacks the essential property of cast iron, viz., its extreme brittleness." Malleable cast iron was generally made by subjecting ordinary castings, preferably of charcoal cast iron, to a process of decarburizing and annealing in an annealing furnace. It is the practice now to select a suitable pig iron and remelt it in an air furnace instead of in the cupola — the air furnace possessing several advantages over the cupola for this purpose. The resultant "hard" or "white" castings contain little or no graphitic carbon and are treated in the usual manner as follows: The castings are packed in hematite ore or peroxide of manganese contained in closed cast-iron boxes. The furnace is raised rapidly to the maximum temperature, and at the close of the operation allowed to cool very slowly. With ordinary castings, the operation requires from two to five days, while the larger pieces may take as long as two weeks. Malleable cast iron, though very brittle when hot, may be hammered into any desired shape when cold. The following data was compiled by Professor Johnson:

	Total Carbon	Combined Carbon	Graphitic Carbon	Manganese	Silicon	Phosphorus	Sulphur
Before Annealing	3.04	2.85	0.19	0.21	0.73	0.154	0.050
After Annealing.	2.66	0.31	2.35	0.21	0.72	0.153	0.050

Loss of carbon, 0.38; maximum tensile strength per square inch, 49,810; elongation 6.23%. All bars were cylindrical in section and $\frac{1}{2}\frac{3}{8}$ inch in diameter. They were not machined, as skin is about twice as strong as the interior per unit of area. These figures represent an average of 42 test bars, annealed 108 hours.

233. Annealed Castings. Castings may be annealed by packing them in a cast-iron box with a mixture of one half bright cast-iron turnings or filings and one half pulverized charcoal. To keep the castings from warping, and to heat them more uniformly, there should be a layer of the mixture between them. The "pots" are then placed in the oven and brought to a bright cherry red, when they are allowed to cool off. If very soft castings are desired, the furnace should be held at a bright cherry

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red for two or three hours. It is absolutely necessary that the castings be left in the box to cool off.

234. Case-hardened Castings. The surface of cast iron may be hardened in the following manner: The piece is heated to a cherry red, and the surface rubbed or coated with potassium cyanide or potassium ferro-cyanide; it is then suddenly chilled by dipping in water. The cyanide, by carbonizing the iron to about a depth of $\frac{1}{32}$ inch, converts it into steel, which we know may be hardened by heating and suddenly cooling.

Castings may also be case-hardened by a process similar to that of producing malleable iron, with the exception that, instead of imbedding in the ore, the pieces are imbedded in granulated raw bone. After packing, the boxes are luted with clay and covered. The furnace is then brought to a bright cherry red, and held at that heat from three to ten hours, according to the depth of the case-hardening desired and the size of the pieces to be case-hardened, after which the pieces are removed from the boxes and suddenly cooled.

The Colliery Engineer Co. print the following formula for a case-hardening solution for cast-iron dies: "Dies, etc., made of cast iron may be case-hardened by heating to a cherry red, and then chilling them in the following solution: 1 quart of oil of vitriol, 4 pecks of salt, 8 pounds of alum, 1 pound of yellow prussiate of potash, 1 pound of cyanide of potash, 2 pounds of saltpeter, which ingredients have been dissolved and mixed in 40 gallons of water, the cyanide of potash and yellow prussiate of potash being dissolved in hot water and the others in cold. If one heating and chilling does not harden the die enough, the process may be repeated.

235. Uses, Adaptability and Comparison with Wrought Iron and Steel. Comparing cast iron with wrought iron and steel, we have: cast iron is more easily given, by casting, any desired shape. It oxidizes less easily, that is, rusts less than wrought iron or steel; it has a very high compressive (crushing) strength. On the other hand, it is liable to hidden defects, rendering its strength uncertain. It cannot be forged, and does not withstand shocks and jars. It stretches but little, and owing to its brittleness breaks off with but little warning. It is also subject to internal stresses, set up from unequal cooling in the mold; its tensile strength is comparatively low. It is used by engineers in con-

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struction, where great compressive strength is desired, and in machine details where shape, mass and weight are of more importance than strength.

Wrought Iron

241. Manufacture — Norway, Charcoal, Puddled and Fagot Irons. Wrought iron is the product obtained by extracting the carbon from cast iron, by passing the blast through it or over it, while it is in a molten condition. During the operation, the oxygen of the air unites with the carbon in the iron, and passes off as carbonic acid gas. This process leaves the iron porous and pasty; it is now hammered or rolled into ingots or blooms, and forged into bars or shapes. Sometimes it is cast and the bloom reheated and rolled; in either event it is necessary — to obtain good iron — that it be reheated and rolled several times in order to render the product flawless and homogeneous. The excellence of Norway and other Swedish irons is due largely to the fact that charcoal, being free from sulphur, is used during the process of melting; although part of the good qualities are due, in a measure, to the purity of the ore.

The best grades of charcoal iron should successfully withstand the test of being bent double, hammered down and straightened while cold, without showing signs of fracture.

In the puddle process of producing wrought iron, the cast iron is melted in an open hearth with iron ore, which contains the necessary amount of oxygen; the flame passing over the mass and removing the impurities. It will be seen that wrought iron is the result of a series of welding operations which give to it its fibrous nature.

What is known as fagot iron is the product obtained by welding together wrought-iron scraps, which are subsequently forged into the desired shape.

The chemical composition of a good pure wrought iron whose tensile strength was 51,000 pounds was: silicon .073, phosphorus .078, sulphur .005, manganese .005, carbon .042, and slag .974, the values being given in fractions of 1%. However, it is found that the marked difference in the qualities of irons are caused more by different methods of treatment than by difference in composition.

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242. Properties. Comparing wrought iron with cast iron, we have: wrought iron is the tougher and is capable of withstanding a greater tensile and transverse stress than cast iron. It is more capable of withstanding shocks and also stresses due to changes in temperature; possesses greater ductility and gives more warning of fractures. On the other hand, wrought iron cannot be melted and cast, nor is it easy to give to it a desired shape. However, two pieces of wrought iron, when subjected to a proper temperature, may be welded — united by a process of hammering when at the proper temperature.

243. Commercial Designation. The commercial terms indicative of the wide variation in the quality of wrought iron are: common bar, best, double best, triple best, and cold rolled. The process of cold rolling not only greatly increases the elastic limit and the strength, but produces on the iron a polished surface. This latter process, however, reduces its ductility.

244. Working. Wrought iron is the most easily worked material with which the smith has to deal. Owing to the lack of carbon in its composition, it does not harden by being suddenly cooled from a high temperature; however, it may be case-hardened in a manner similar to that described for case-hardening cast iron.

Steel, Commercial Steels and their Production

251. Classification. Since the extraction of carbon from cast iron renders the wrought iron tough, ductile and soft, it follows that it is possible to obtain such a mixture of wrought iron and carbon as will possess some of the excellent qualities of both wrought iron and cast iron. This product, known as steel, may be divided according to its process of manufacture into four general divisions which, according to Metcalf, are:

Converted or Cemented Steel.

Crucible-Cast Steel.

Bessemer { Acid / Basic } Cast Steel.

Open-Hearth { Acid / Basic } Cast Steel.

252. Converted or Cemented. Converted or cemented steel is divided, according to its manufacture, into blister, German,

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shear or single-shear and double-shear steel; however, though the process of production of these brands be interesting, they have been superseded by the cast steels.

253. Blister. Blister steel is manufactured by surrounding small ($\frac{3}{4}$ inch square) bars of charcoal iron by some form of carbon, such as charcoal or bone ash, in a suitable vessel, which is hermetically sealed, and then subjected to an even high temperature for some days. Under this action the carbon penetrates the iron, and when the bars are removed they are found to be covered with scales or blisters, having been converted from tough wrought iron to highly crystalline steel. Oftentimes a better grade of steel is produced by removing the scales and blisters and again subjecting the bars to a cherry heat for a few days, thus producing a more uniform distribution of the carbon.

254. German. German steel is produced by heating blister steel and rolling it directly into finished bars.

255. Single and Double Shear. Single-shear steel is produced by subjecting blister steel to a high temperature, welding it under the hammer, and then rolling it into bars.

Double-shear steel is produced by welding together broken bars of single-shear steel, which are then hammered or rolled into desired shapes, thus producing a more uniform product.

256. Crucible Cast. Crucible-cast steel may be obtained in two ways, the aim being to produce a steel uniform and homogeneous in structure. In the first, bars of blister steel are broken up and melted in a crucible, the contents of which are then cast into ingots and rolled into bars. This produces the finer qualities of the crucible and cast steels now on the market. By far the larger portion of cast steel is produced by packing Swedish iron, together with charcoal, in a sealed vessel the contents of which are then melted and poured — with the contents of several other similar vessels — into a large ladle. The metal in this large ladle is then cast into ingots which are subsequently forged under the hammer or with rolls.

257. Bessemer. Bessemer steel. The soft or mild machinery steels of commerce contain but little carbon, show but a few of the characteristics of steel, and are but little better than iron. They are produced by both the Bessemer and the open-hearth processes. The Bessemer process consists of decarbonizing molten cast iron by blowing through it a blast of air; the requisite amount

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of carbon is then obtained by adding to it sufficient quantities of Spiegeleisen — an iron of known chemical composition, rich in carbon and manganese. After this product is thoroughly mixed, it is cast into ingots which are subsequently rolled or forged into desired bars and shapes.

258. Open Hearth and Puddled. The open-hearth or puddled steels are made by what is known as the Siemens-Martin process, which consists of adding to cast iron which has to some extent been decarbonized, in an open-hearth furnace, a certain amount of scrap wrought iron. The molten mass is continually stirred until it becomes somewhat spongy and granular, after which the mass is taken out and cast into ingots, which are subsequently forged or rolled into the desired shape. By a judicious proportioning of the wrought and cast iron, steel of almost any desired grade of carbon may be produced.

259. Carbon Steels. This term generally applies to steels used for cutting and small tools and is what might be termed a pure steel as it is a combination of iron and carbon, other elements appearing only as impurities or as they have been inserted in small quantities by the steel-maker to assist in some detail in the process of manufacture. The carbon content ranges from 50 to 150 points, that is, .5% to 1.5%. An increase of .01% increases the tensile strength about 1000 pounds per square inch, and while 50-point carbon is hard enough for some cutting tools, 100-point carbon gives, when tempered, the limit of hardness of this kind of steel, being all but hard enough to resist being scratched by a heavily loaded diamond.

Structural steel contains from .02% to .35% carbon.

The following table from data by F. W. Taylor gives the chemical analysis of some of the best grades of ordinary carbon-tool steels, hardened in water, together with their relative cutting speeds.

Kind of Steel	Carbon	Manganese	Silicon	Phosphorus	Sulphur	Speed in Medium Steel
Jessup	1.047	0.189	0.206	0.017	0.017	16 Ft.
Midvale O.H..	0.992	0.318	0.256	0.037	0.020	16′-8″
Midvale O.H..	0.681	0.198	0.219	0.024	0.011	——
Sanderson....	1.072	0.291	0.148	0.014	0.011	15′-8″
Stirling Spec..	1.240	0.156	0.232	0.016	0.006	16 Ft.

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Steel, Alloy and High Speed

261. Chrome Steel. Carbon steel, by the addition of 1% or 2% of chromium, produces a metal, not only extremely hard but one which is self-hardening. It is fine-grained and very hard in the hardened state but does not stand redressing, becoming inferior because of the rapid oxidation of chromium as it is redressed. J. W. Langley says that chrome, like manganese, is a true hardener of iron, even in the absence of carbon.

A tool of high chromium, 3% to 4%, with the proper amount of tungsten, invariably produces a high-speed tool steel even when the manganese content is low. The best high-speed tool steels now contain from 5% to 6% of chromium. It is suitable to use in the manufacture of some metal-cutting tools or armor plate and shells.

262. Nickel Steel. Nickel steel may be purchased in the open market with a nickel content from 0 up to 35% and a carbon component between .1% and 1.%. It possesses a remarkable tensile strength and ductility, a high elastic limit and homogeneity and a great resistance to cracking. Tests show a tensile strength of from 100,000 to 275,000 pounds per square inch, with an elastic limit of from 40,000 to 74,000 pounds per square inch and an elongation of from 3% to 55%.

Kent says that sudden failure or rupture of this steel would be impossible, for it seems to possess the toughness of rawhide with the strength of steel. An alloy of 27% nickel is practically non-corrodible and non-magnetic. The effect which nickel produces on steel is to raise the elastic limit and to give great toughness under shock, the nickel evidently preventing the shortness caused by the carbon to the extent of even assisting the latter to exercise its strength-giving properties. The effect of nickel is not always uniform; thus percentages up to 8% increase the tensile strength and elastic limit, while in the zone between 8% and 15% brittleness is produced; but at 16% the strength and elastic limit are returned; again, steel with 2% of nickel and .9% of carbon cannot be machined. With less than 5% of nickel it can be worked cold provided the carbon content be low; as the proportion of nickel raises cold working becomes difficult, though it forges easily whether the nickel content be great or small.

The manganese content in nickel steel is most important; it

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would seem that without its assistance in proper proportion, the conditions of treatment would not be successful. The carbon content is also important for upon it depends the strength and hardness. In the heat treatment of this alloy, which is always beneficial, nickel overcomes the tendency to burn, and the extent to which it may be swayed by heat treatment is illustrated in the following table by E. F. Lake:

Hardness	Tensile Strength Lbs. Per Sq. In.	Elastic Limit Lbs. Per Sq. In.	Elongation in 2″ Per Cent.	Reduction of Area Per Unit
Annealed.....	88,000	60,000	28	58
Medium Hard ..	130,000	130,000	20	6
Hard	220,000	190,000	12	37
Very Hard.....	225,000	225,000	8	19

The composition of the above steel was Nickel, 3%; Carbon, 0.30%; Manganese, 0.40%; Phosphorus, 0.05%, and Sulphur, 0.04%.

As is well known, nickel steel is eminently adapted for ordinance work; and armor plate, surface-hardened by the Harvey process, is used in all the navies of the world. On account of its ability to withstand heavy shock and torsional tests, nickel steel is adapted for crank and propeller shafts, connecting rods, explosive engine and automobile work.

263. Nickel-chrome Steel. An alloy of nickel, chrome and carbon, developed during the last decade, bids fair to occupy as high a place as any commercial steel manufactured. It is used chiefly for high-grade machinery that requires a steel of great resistance to shock and torsional stresses, high elastic limit and great tensile strength. Chromium, in conjunction with nickel, overcomes a tendency of lamination and produces an elastic limit beyond all expectations. When nickel chrome steel is given a proper heat treatment, it is practically a homogeneous mass showing no grain or fiber and so manifesting an extraordinary power to resist shocks.

The action of chromium in the alloy becomes conspicuous above a content of 1%; and with 2% great difficulty is experienced in cutting cold without the use of a special tool steel.

Nickel-chrome steel is used largely for auto work, propeller shafts, and where the price is sacrificed to obtain quality. The

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following table, the last two lines of which give the specifications adopted by the Association of Licensed Automobile Manufacturers, gives the composition of nickel-chrome steels together with their remarkable physical properties:

Kind of Steel	Nickel	Chromium	Carbon	Silicon	Manganese	Phosphorus	Sulphur	After Heat Treatment			
								Tensile Strength Lbs. Per Sq. In.	Elastic Limit Lbs. Per Sq. In.	Elongation in 2"	Reduction of Area
Nickel-Chrome..	3.30	1.40	.31	.20	.40	.012	.028	155,000	132,000	38	16
Chrome-Nickel..	1.60	4.41	.25	.20	.35	.012	.013	185,000	160,000	14	48
25C Auto Mfgr..	1.50	.80	.25	—	.40	.03	.035	130,000	100,000	12	30
45C " " .	1.50	.80	.45	—	.40	.03	.035	180,000	140,000	8	20

264. Manganese Steel. The addition of ferro-manganese to iron or steel produces manganese steel, the carbon content of which is of considerable proportion, being incidental and almost unavoidable rather than intentional. Manganese, like carbon, is a true hardener.

The following table is indicative of the peculiar properties which manganese gives to steel:

0% to 1¼%.....Little or no appreciable effect if carbon content be low.

2½% to 6½%....Strength and ductility diminish while hardness increases: remarkably brittle when cold, even with low carbon content.

4½ %to 6%.....With a carbon content of but .37% is reported to be so extremely brittle that it can be powdered under a hammer when cold and is ductile when hot.

6½% to 8%.....Strength and ductility are increased while the magnetic quality decreases.

10% .....Is very ductile and if not tough may be improved by water quenching. Strength equals that of crucible steel; it is too hard to file.

12% .....Lineham says this metal is entirely lacking in strength no matter what the treatment, but the strength returns in its maximum at 14%. Relating nothing regarding the 12% content, Howe states that as the proportion of this element rises above 6%, the strength and ductility both increase while the hardness diminishes slightly.

13% .....It is practically non-magnetic.

14% .....The maximum of both strength and ductility is reached. With this proportion the metal is so hard that it is difficult to cut with steel tools.

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15% to 17%....The ductility falls off abruptly, the strength remaining nearly a constant.
18% .....Strength diminishes suddenly.

Manganese steel is quite free from blowholes, is strong, ductile and hard, more fluid than cast steel, but pipes badly and when cast requires large feeding gates. It is difficult to mold on account of its having a shrinkage of $\frac{5}{16}$ inch per foot. It welds with great difficulty and its toughness may be increased by quenching from a yellow heat. Its enormous electric resistance is almost constant with changing temperatures and it is low in thermal conductivity. Such a remarkable combination of qualities, of great hardness which refuses to be diminished by annealing, a high tensile strength with astonishing toughness and ductility, combined with its non-magnetic qualities, would make this the ideal metal but for the fact that its hardness prevents its being machined or fitted by any but abrasive processes.

In its ability to resist wear, manganese steel is the most durable metal known for hardness, toughness and malleability. It is suitable for steam shovel teeth, dredge pins, plow points, fine rails, frogs, switches and crossings, crushing rolls for ore, rock screens, gear sprockets, or anything where a grinding wear in dust is required. The best composition is manganese from 12% to 15%; carbon not over .5%; phosphorus not more than .4%; and sulphur not more than .4%. Manganese castings should always be annealed.

265. Silicon Steel. Metcalf makes the following trite remarks concerning silicon steel: "Steel containing 3% of silicon has been put upon the market and great claims made for it. It is exceedingly fine-grained and hardens very hard; it is brittle, much more liable to crack in hardening than ordinary steel and it is not nearly so strong as carbon steel . . . altogether, then, silicon steel is expensive and it presents no very good qualities in compensation."

266. Tungsten or Mushet Steel. Tungsten or self-hardening steel is a special cast steel — an alloy of iron, carbon, tungsten and manganese, some brands of which contain chromium. It was erroneously supposed for a long time that tungsten was the metal that gave to this alloy its peculiar properties; however, it is now conclusively proven that the manganese together with carbon are the hardeners and that chromium improves the quality

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of the steel. It is not to be inferred that tungsten is an unnecessary constituent for it plays an important part as the mordant by which the alloy produced contains a larger combined carbon content. This steel retains its hardness almost up to a red heat.

Regular tungsten steels contain from 5½% to 10% of tungsten. Professor Langley remarks in this connection: "I have made steel containing as high as 25% tungsten and very little carbon which was so soft that it could be readily touched with a file." Had the good professor accidentally burned a tool of this steel, as was done by the careless smith during the Taylor-White experiments, and then tried to see just what work it would do, in all probability we would have had our high-speed steels some twenty years sooner.

Tungsten steel is more widely known as self-hardening or air-hardening steel, from its property of hardening when allowed to cool in quiet air. It is so hard in its ordinary condition that it cannot be machined and, like all steels of this class, has to be forged to the desired shape. Self-hardening steel tools are essentially roughing tools, other brands of steel proving more efficient for finishing. Its hardness is not improved by the ordinary tempering; it may be annealed, however, by keeping it at an orange heat for from 24 to 36 hours and allowing it to cool, imbedded in the furnace in hot sand or ashes for the same length of time; it may then be machined. Its chief use is for cutting tools.

Perhaps it will be of interest to note that of ten samples of the celebrated Damascus steel of the Orient analyzed by Duc de Luynes, eight contained tungsten, two of them in quantities of .52% to 1.% and all samples contained nickel, some as high as 4%.

267. Vanadium and Chrome Vanadium Steels. As has been previously noted, vanadium bids fair to become a rival of carbon in its ability to produce great changes in steel by the addition of very small percentages. Vanadium has a tendency to cause brittleness. E. F. Lake, reporting on this alloy steel, states that it compares favorably in static strength with any of the steels and that it exceeds all others in its ability to resist dynamic stresses. An instance is given by another steel man where the addition of .25% of vanadium increased the tensile strength of a carbon manganese steel 65%, while the elastic limit was in-

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creased 68%. This alloy of carbon, manganese and vanadium, with an addition of 3.34% of nickel, had its tensile strength increased 61% from 94,528 to 152,531; while the elastic limit was raised 64% to 112,539 with an elongation of 26%.

On account of its brittleness, vanadium steel should always be annealed, and when annealed at about 1475 degrees and oil-tempered, as will be seen from the tables given below, some remarkable properties are patent. The composition of the steel tabulated is as follows:

Vanadium, .17%; Chromium, 1.%; Carbon, .25%; Manganese, .5%.

	Tensile Strength Lbs. Per Sq. In.	Elastic Limit Lbs. Per Sq. In.	Elongation in 2"	Reduction of Area
Annealed at 1475 deg.	87,640	64,400	29	59
Annealed at 1475 degrees, Oil tempered at varying quenching temperatures...	125,000	103,000	21	56
	127,800	110,100	20	58
	130,500	124,000	17	62
	138,000	127,500	18	65
	147,000	140,750	17	57
	212,000	200,000	12	51
	232,750	224,000	11	39

The best high-speed cutting steel produced by Taylor-White to this date (1907) has a vanadium content of .29%.

268. Aluminum, Cobalt, Tin, Titanium and Other Steels. *Aluminum, Cobalt, Tin and Titanium.* As will be gathered from a reading of Sect. 218, there is nothing in the mechanical properties of these four steels which would lead any one to make a preference in their favor. The small percentage of aluminum which remains in the steels, not passing off in the slag, up to a content of .5%, increases the tensile strength and raises the elastic limit, but the elongation and reduction of area are materially injured.

Kent classes the action of aluminum along with that of silicon, sulphur, phosphorus and copper as giving no increase to the hardness of iron, in contradistinction to carbon, manganese, chromium, tungsten and nickel. Aluminum seems to combine in itself the advantages of both silicon and manganese, but so long as alloys containing these metals are so cheap and aluminum so dear, its extensive use seems hardly probable.

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Other Steels. *Invar* is the name given to a metal which is a non-expanding nickel steel, having an approximate composition of 64% iron, 35% nickel and the remaining 1% made up of carbon, silicon, manganese, etc. Because it is non-expanding, Invar has been found to be exceedingly valuable in the construction of scientific instruments.

Resista steel, so called, has a chemical composition of 79% iron, 6% manganese, 15% nickel and a tensile strength of 68 tons, with an elongation of from 50% to 70%.

269. High-speed Cutting Tool Alloys. As indicating the four epochs in the history of tool steels, the carbon tool steel era; the self-hardening steel era; the discovery of high-speed tools; and modern high-speed tools, the following table, taken from President Taylor's monumental A. S. M. E. address, on the Art of Cutting Metals, is given.

The table gives the chemical analysis of four steels which are typical of the various eras in the development of metal-cutting tools.

Make of Steel	Per Cent. Tungsten	Per Cent. Chromium	Per Cent. Carbon	Per Cent. Manganese	Per Cent. Vanadium	Per Cent. Silicon	Per Cent. Phosphorus	Per Cent. Sulphur	Speed in Ft. Per Min. in Cutting Medium Steel
Jessup	—	0.207	1.047	0.189	—	0.206	0.017	0.017	16
Mushet, Self Hardening, Tungsten	5.441	0.398	.015	1.578	—	1.044	—	—	26
Original Taylor-White	8.00	3.80	1.85	0.30	—	0.15	0.025	0.030	58 to 61
Best Modern High Speed Taylor-White	18.91	5.47	0.67	0.11	0.29	0.043	—	—	99

The chemical composition of the medium steel forging used for these cutting tests is as follows:

Carbon, 0.34%; Manganese, 0.54%; Silicon, 1.76%; Phosphorus, 0.037%; Sulphur, 0.026%; Tensile Strength, 70,280 pounds; Elastic Limit, 34,630 pounds.; Angle of tools used on medium steel forgings, Clearance Angle, 6 degrees; Back Slope 8 and Side-Slope 14 degrees.

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Steel, Manipulation

271. Steel Castings. Steel castings, similar to iron castings, may now be made in almost any desired shape; the greatest difficulty having been experienced in the production of suitable molds rather than in the handling of the material. The open-hearth steel is considered superior to the Bessemer for this class of work.

272. Structure. As we have already learned, steel is a chemical compound of iron and carbon generally containing some other elements as silicon, sulphur, phosphorus, manganese, etc. It contains no free or graphitic carbon as does cast iron; its tensile strength is greater than wrought iron and its compressive strength though less than cast iron is greater than wrought iron. The strength of steel varies greatly with its purity and the amount of carbon which it contains. Unlike wrought iron it is fusible, unlike cast iron it can be forged; and with the exception of very low grades, possesses the valuable quality of hardening when suddenly cooled from a proper temperature. From the matter in the early part of the subject, we discover that steel is made in one of the three following ways: 1, by adding carbon to wrought iron; 2, by removing carbon from cast iron; 3, by melting together cast and wrought iron in suitable proportions.

273. Treatment. The accompanying table (Fig. 273), illustrating the effect produced by various processes of working, is compiled from data obtained by Professor J. W. Langley.

Number	Treatment	Angle of Cold Bend in Degrees	Carbon		Diameter In.	Elastic Limit, Pounds Per Sq. In.	Tensile, Pounds Per Sq. In.	Elongation, Per Cent.	Reduction of Area, Per Cent.
			Total	Semi-Graphitic					
1	Cold-hammered Bar	153	1.25	.47	.575	92,420	141,500	2.00	2.42
2	Bar Drawn Black	75	1.25	.47	.577	114,700	138,400	6.00	12.45
3	Bar Annealed .	175	1.31	.70	.580	68,110	98,410	10.00	11.69
4	Bar Hardened and Drawn Black	30	1.09	.36	.578	152,800	248,700	8.33	17.9

Fig. 273.

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The total carbon given in the table was found by the color test, which is affected, not only by the total carbon, but by the condition of the carbon.

The analysis of this steel is:

Silicon	.242	Manganese	.24
Phosphorus	.02	Carbon (true total carbon by combustion)	1.31
Sulphur	.009		

Note. Both the Bessemer and open-hearth processes are used for the production of structural steel; however, according to Metcalf, for fine boiler plates, armor plates and gun parts, open-hearth steel has won its place as completely as has the crucible for fine tool steels, or the Bessemer for rails.

274. Working. Great care should be exercised in working steel, as costly materials may be rendered useless by improper handling on the part of the operator; the defects thus easily caused are overheating, burning and checking. In general use a very gentle blast with a good body of fuel, and forge at as low a heat as possible. Harden at a low cherry red — 1450° to 1500° Fahr. Light, rapid blows with the hammer as the color is dying out have a peculiarly beneficial effect on the grain of the piece so treated; this is called "hammer refining."

275. Theory of Hardening. As other elements, such as small quantities of manganese, silicon, phosphorus and sulphur appear in carbon steel rather as incidental than intentional contents, we may neglect the others and concern ourselves with carbon as the true hardener. Broadly speaking, carbon may exist in the steel in either of two forms or states; viz., as cementite, which Mr. Taylor calls "hardening carbon," or as pearlite, termed "softening carbon." In the annealed bar as it is received from the dealer, the carbon exists as pearlite or "softening carbon." Before the steel can become hard, the pearlite must change to the "hardening carbon," cementite. The change is effected by heating the steel through a certain range of temperatures which have been determined by scientists and which conform closely to the following description:

It is a matter of general knowledge that to harden steel it must be heated to what is empirically known as a low "cherry red," a temperature close to 1450° F. When the temperature passes slightly above 1450° F. the pearlite is entirely changed to

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cementite, provided a certain short interval of time be allowed for the process because it takes time to effect the change. If the temperature is allowed to drop below 1400° F. the cementite will change back to pearlite; *i.e.* from "hardening" to "softening carbon," and the change may be made over and over again.

The fact that it takes a certain appreciable time for the change to take place enables us by quenching to hold or arrest this transformation at any desired point. If a tool heated above 1450° be rapidly and continuously cooled, by quenching in water or otherwise, down below a temperature of 392° F., the cementite or "hardening carbon" will not have had time to change to pearlite or "softening carbon" and will remain trapped in the steel, as it were, in its hard or diamond-like form. The trapped cementite gives to the whole tool its hardness, and so long as the temperature remains below 392° F. it cannot be changed back to pearlite. Tools hardened in the above manner are generally too hard and brittle to be used for ordinary machine shop work and have to be tempered or softened. If we had stopped the process of cooling at any point between 1450° and 392°, even for a comparatively short time, then to a greater or less degree the change from cementite to pearlite would have taken place and the tool would have been softer and less brittle. If, now, after having cooled the tool rapidly from 1450° down below 392° F., we reheat it to some point above 392° and below 600° F., the change from cementite to pearlite begins to take place, the tool becoming softer and softer until 600° is reached, when it will be found entirely soft and the cementite changed to pearlite.

With the aid of a Le Chatelier pyrometer, it was discovered that as the carbon changed from cementite to pearlite, so definite and powerful was the molecular change in the structure of the steel, that the heat developed was sufficient to hold or even raise the temperature slightly. This occurs at 1400° F. and it was for this reason that this point became known as the "reheating point," "recalescence point" or "critical point." "All tool steels, whether carbon or high speed, have at least one critical point," says Mr. Taylor, "and many of them have two or more in cooling from a high heat to the normal temperature of the air." At every critical point, then, some internal molecular change takes place.

The lower critical point of carbon tool steel, at which point softening or tempering takes place, broadly speaking, lies some-

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where between 392° and 600° F.; and the upper critical point occurs about 1450° F. when the change from pearlite to cementite takes place. It is important to know that the critical points do not occur at the same temperatures when cooling; — *i.e.* when the heat is going down — as when heating — *i.e.* when the

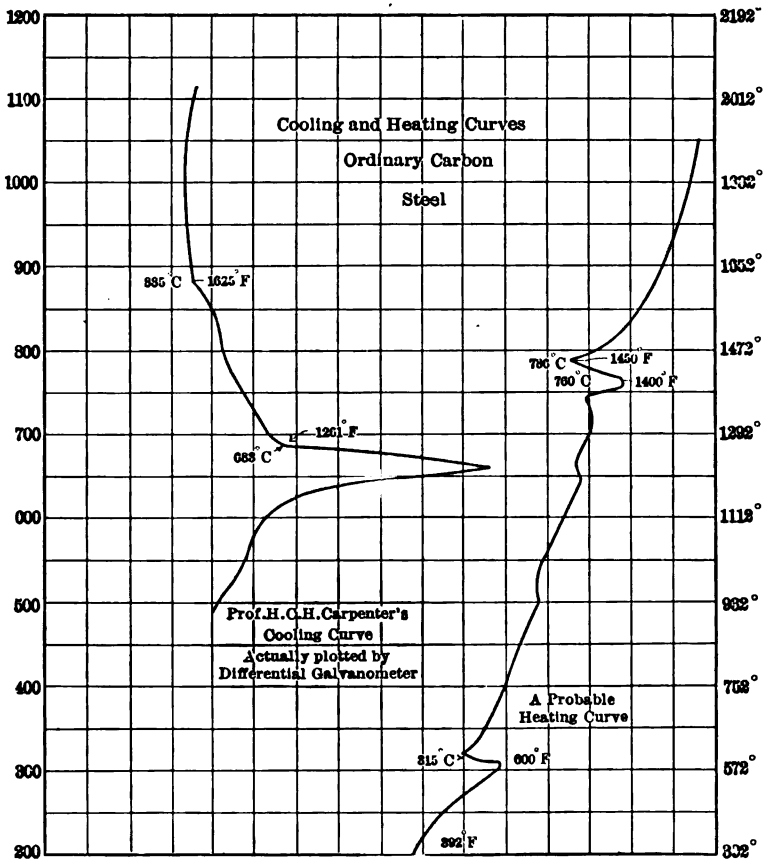

FIG. 275*a*. — Carbon Steel Curves.

heat is going upward — indicating that the internal changes occur at different temperatures. See Fig. 275*a*.

By a comparison of Mr. Taylor's curves herewith, Fig. 275*b*, it will be noted that the principal critical point in heating is higher by about 160° F. than the principal critical point in the cooling, and therefore the operator who is hardening carbon

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steel is much more interested in the heating than in the cooling curve, as it is to the former he must look for a point just above

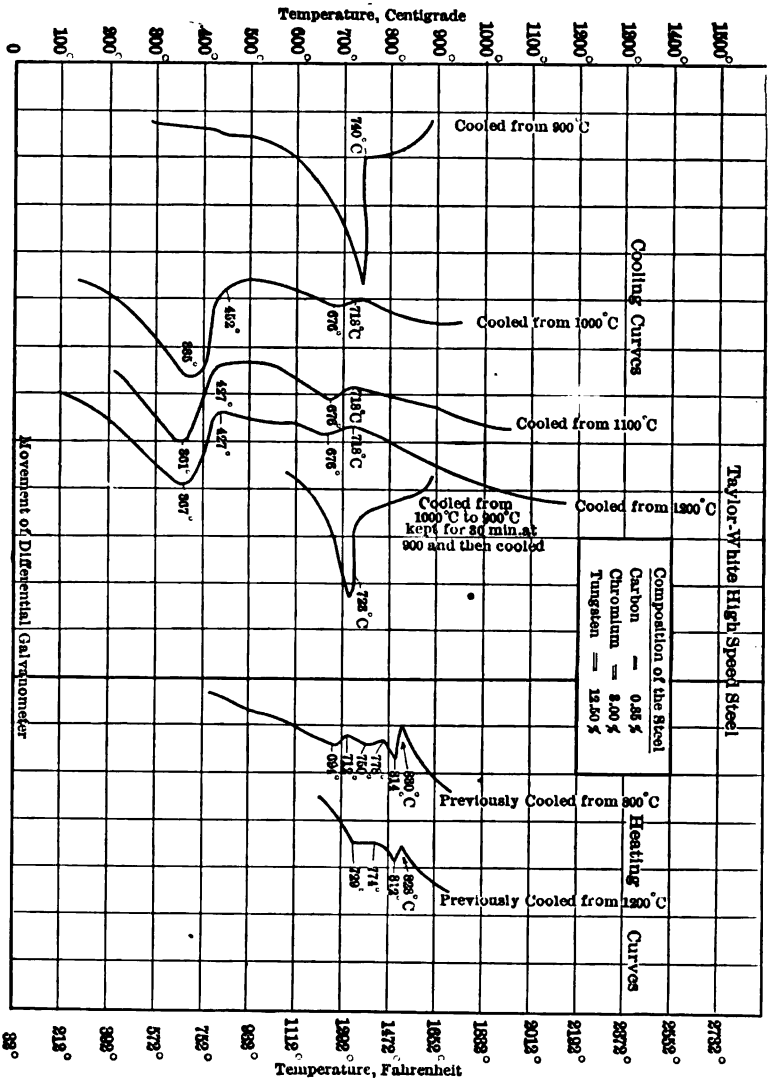

FIG. 275b. — High-speed Steel Curves.

which he must heat his tool in order that it may harden thoroughly, preserve a fine grain and be free from the brittleness and other troubles which come from the overheating.

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276. Hardening and Tempering. When a clean piece of steel, hardened or unhardened, is exposed to heat in air it will assume different colors as the heat increases. It is a well-established fact that these colors are due to thin films of oxide that are formed as the heat progresses. These colors are as useful as beautiful and furnish an unvarying guide, with a given grade of steel, as to the condition of the hardened tool. Tempering steel is the act of giving it, after it has been shaped, the hardness necessary for the work it has to do. In most cases this is done by first hardening the piece, generally a great deal harder than is necessary, by suddenly cooling from a low cherry heat 1450° to 1500° Fahr. and then toughening it by slow heating and gradual softening until it is just right for the work it has to perform. A modification of this latter process consists in hardening the cutting portion of the tool by a momentary chilling, and then allowing the still heated portion to raise the temperature of the chilled and hardened portion to the desired point, when further rise is prevented by a sudden quenching. The word temper, when applied to steel, has, unfortunately, two diverse meanings. The steel manufacturer uses the word to designate the amount of carbon which steel contains; and the worker the color of the oxide at a given temperature.

277. Table of Tempering Data.

Manufacturer's and Purchaser's Data			Temper	Worker's Data		
Characteristics	Suitable for	Manufacturer's Meaning for Word Temper. Points. Carbon		Worker's Meaning for Word Temper. Color	Temperature of Piece at this Color. Fahr.	Tools hardened at this Color and Temperature
Very difficult to forge and easily burned	Large lathe planer and boring tools for machining rolls, tool steel and tires.	150 Pt. C.	Very High	Light Straw	430	Scrapers, scribers, files, lathe and planer tools for hard materials
	Large lathe and planer tools and med. size dies.	135				
	Taps, reamers and drills.	125				

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277. Table of Tempering Data (*continued*).

Manufacturer's and Purchaser's Data			Temper	Worker's Data		
Characteristics	Suitable for	Manufacturer's Meaning for Word Temper. Points. Carbon		Worker's Meaning for Word Temper. Color	Temperature of Piece at this Color. Fahr.	Tools hardened at this Color and Temperature
Bears heat not above cherry redness; great care is required in working.	Screw cutting dies, chisels, punches, and milling cutters.	115	High	Straw	460	Milling cutters, lathe tools, taps, dies, reamers, punches and dies, hammer faces, drills.
	Cold chisels, punches, dies, large taps, and milling cutters and small shear knives.	105				
Easily burned, requires skilful manipulation in working.	Large punches, shear blades, large dies, and some blacksmith's tools.	95	High Medium	Brown	490	Cold chisels, drills, drifts and brass working tools, shear knives.
	Stamping dies, hammers, cold sets, track chisels and blacksmith's tools. Lathe, planer and machinist's tools.	85				
A good common tool steel.	Lathe, planer and machinist's tools. Swages, flatters, cupping tools and blacksmith tools generally.	75	Medium	Brownish Purple	540	Cold chisels, some hack saws, woodworking tools.
Works somewhat like wro. iron.	Tires, etc.	60 to 45	Mild	Dark Blue	570	Springs, fine saws.
Tempers slightly.	Boiler Plates and axles.	35 to 20	Low	Pale Blue	610	Common saws, some springs.
Does not temper.	Some machine parts	Below 20	Soft	Greenish Blue	630	Too soft to be useful.

Fig. 277.

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Note. The uses given for temper colors and the other data in the above table are to be taken as merely giving a good general idea; experienced men are guided by results, and select and temper in the way that gives these results.

The tensile strength of steel varies from 46,800 pounds to 248,700 pounds per square inch.

100 carbon steel, *i.e.* steel containing 1% carbon, is the strongest in every way, as this percentage is about the saturation limit.

278. The Taylor-White Treatment of Tool Steels. Mr. Taylor says, referring to their invention: "By far the most important of the discoveries made by us, and that which led to the modern high-speed tools, was the discovery that when tools made from tool steel, old in its chemical composition (containing not less than .5% of chromium and not less than 1% of tungsten, or its equivalent), were treated in a new and completely revolutionary manner to an extraordinarily high heat — a heat so high that it would have utterly ruined ordinary tools — this treatment imparted an entirely new property or quality to a cutting tool; viz., the property called "red hardness." And it is this new property which enables these tools to run at their high cutting speeds.

The treatment is described as follows: The first or high heat treatment consists of heating the tool,

(*a*) Slowly to 1500° F.

(*b*) Rapidly from that temperature to just below the melting-point.

(*c*) Cooling fast to below the breaking-down point; *i.e.* 1550° F.

(*d*) Cooling either fast or slow from this point to the temperature of the air.

The second or low-heat treatment consists of heating the tool,

(*a*) To a temperature below 1240°, preferably to 1150° for a period of about five minutes and

(*b*) Cooling to the temperature of the air, either rapidly or slowly.

Alloys, Bronzes, Brasses, etc.

281. Properties and Characteristics. Alloys may be made of various metals that have an affinity for one another, and the

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mixtures have properties and characteristics which neither of the metals possess. For instance, copper is a soft, red-colored, tenacious metal of brilliant luster; is malleable and ductile, and fuses at about 1930° F.; its tensile strength is from 20,000 to 30,000 pounds per square inch. Tin, on the other hand, is a white, soft, lustrous metal, malleable and having but little strength; it fuses at 442° F., and has a tensile strength of 3500 pounds per square inch. Two parts of copper will combine with one part of tin, forming a homogeneous compound that is gray in color, very hard and brittle.

282. Bronzes, Copper-Tin Alloys. Alloys of copper and tin are known as bronzes. From 1% to 12% of tin increases the tensile strength of copper; from 1% to 8% increases the ductility, and from 1% to 18% the compressive strength. Greater quantities of tin render the metal very hard and brittle; so hard and brittle as to be of little use where strength is required.

283. Phosphor Bronze. The addition of phosphor to copper alloys, deoxidizes the copper oxides, improving many of the alloys in strength, ductility and fluidity. In general, the grain of fracture of phosphor alloys is finer and the color brighter than others. A good phosphor bronze has a tensile strength of 52,000 pounds, with an elongation of 8.4%; it contains 79% of copper, 10% of lead, 10% of tin and 1% of phosphorus. Like ordinary bronzes, the strength of phosphor bronze varies according to the per cent of copper, tin, lead, zinc, etc., in the alloy.

284. Brasses, Copper-Zinc Alloys. Strictly speaking, any alloy of copper and zinc is known as brass. Zinc assists in obtaining sounder castings by giving greater fluidity to the mixture, and proves an excellent deoxidizing agent for the copper. Zinc costing about one fourth as much as tin is used in the alloy wherever such castings will prove suitable.

285. Copper-Tin-Zinc Alloys. By a combination of these metals a very remarkable metal was produced. A metal containing 55 parts of copper, .5 parts of tin, and 44.5 parts of zinc gave, in a test for transverse strength, 72,308 pounds as a modulus of rupture, with a deflection of 3.5; its tensile strength was 68,900 pounds with an elongation of 9.43%. Professor Thurston made an ingenious cast to represent graphically the laws of variation of strength in these alloys. If one side of a triangle represent 0 copper, a second 0 tin and a third 0 zinc, the vertex opposite

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each of these sides represents 100 of each element respectively. On points in a triangle of wood, representing different alloys tested, wires were erected of lengths proportional to the tensile strength, and the triangle then built up of plaster to the height of the wires. The surface thus formed has a characteristic topography, representing the variations of strength with variations of composition. The highest point obtained was a composition of 55 copper, zinc 43 and tin 2, with a tensile strength of 70,000 pounds. The formula for the strongest of these alloys is:

$$\text{Zinc} + (3 \times \text{Tin}) = 55.$$

Illustrating the formula by choosing 7 for the Zinc, we have

$$\begin{aligned} 7 + 3\,\text{T} &= 55 \\ 3\,\text{T} &= 55 - 7 = 48 \\ \text{T} &= 16 \end{aligned}$$

and our composition becomes

7 Zinc, 16 Tin and 77 Copper

i.e. $7 + 16 + 77 = 100\%$

The formula Zinc + 4 Tin = 50 gives a series of alloys having greater ductility together with considerable strength, which may be more easily worked by machine tools; the other series being generally too hard for ordinary machinery.

286. Lead, Use in Alloys. Lead, though having but little affinity for either copper or zinc, is added to assist in giving to the castings a smooth surface; it is also used on account of its cheapness. Should the lead in copper and zinc alloys exceed 3% of the mixture, the result will prove unsatisfactory. Lead alloyed with arsenic is used for making shot, with bismuth for fusible alloys, and with antimony for type metal.

287. Composition of 26 Ordinary Commercial Alloys. In the table below (Fig. 287*a*) is given the chemical composition of the ordinary alloys in every-day use in brass foundries. The table is taken from the *American Machinist*.

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Name of Metal	Copper Lbs.	Zinc Lbs.	Tin Lbs.	Lead Lbs.	Use of Metal
Admiralty Metal ..	87	5	8	—	For parts of engines on board naval vessels.
Bell Metal	16	—	4	—	Bells for ships and factories.
Brass (Yellow) ...	16	8	—	½	For plumbers, ship and house brass work.
Bush Metal	64	8	4	4	For bearing bushes for shafting.
Gun Metal	32	1	3	—	For pumps and other hydraulic purposes.
Steam Metal	20	1	1½	1	Castings subjected to steam pressure.
Hard Gun Metal ..	16	—	2½	—	For heavy bearings.
Muntz Metal	60	40	—	—	Metal from which bolts and nuts are forged, valve spindles, etc.
Phosphor Bronze..	92	—	8 phos. tin		For valves, pumps and general work.
Phosphor Bronze..	90	—	10 phos. tin		For cog and worm wheels, bushes, axle bearings, slide valves, etc.
Brazing Metal	16	3	—	—	Flanges for copper pipes.
Brazing Solder....	50	50	—	—	Solder for the above flanges.

FIG. 287*a*.

In this Table (Fig. 287*b*) is given the composition of various other useful alloys. This table is from Kent, and is gleaned from various sources:

Alloy	Copper	Tin	Zinc	Lead	Antimony	Remarks
U. S. Navy Dept., Journal Boxes	6	1	¼	—	—	Parts
and Guide-Gibs.....	82.8	13.8	3.4	—	—	Per Cent.
Tobin Bronze.....	58.22	2.30	39.48	—	—	"
Naval Brass.....	62	1	37	—	—	"
Composition, U. S. Navy.....	88	10	2	—	—	"
	64	8	1	—	—	Parts
Brass Bearings (J. Rose).....	87.7	11.0	1.3	—	—	Per Cent.
	92.5	5	2.5	—	—	"
	91	7	2	—	—	"
Gun Metal	87.75	9.75	2.5	—	—	"
	85	5	10	—	—	"
	83	2	15	—	—	"
	13	2	2	—	—	Parts

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FIG. 287*b* (*continued*).

Alloy	Copper	Tin	Zinc	Lead	Antimony	Remarks
Tough Brass for Engines.....	76.5	11.6	11.7	—	—	Per Cent.
Bronze for Rod Boxes (Lafond).						
Slightly Malleable.....	82	16	2	—	—	"
Bronze for Pieces Subject to						
Shock	83	15	1.5	0.5	—	"
	20	1	1	1	—	Parts
Red Brass.....	87	4.4	4.3	4.3	—	Per Cent.
Bronze for Pump Casings (La-						
fond).....	88	10	2	—	—	"
Bronze for Eccentric Straps (La-						
fond).....	84	14	2	—	—	"
Bronze for Shrill Whistles.....	80	18	—	—	2.0	"
Bronze for Low-toned Whistles.	81	17	—	—	2.0	"

FIG. 287*b*.

288. Telephone and Telegraph Wire Alloys. Silicon bronze, made of 97 parts of copper and 3 parts silicon, has a tensile strength when in a casting of about 55,000 pounds to the square inch, with an elongation of from 50% to 60%.

This table gives a comparison of copper, silicon-bronze and phosphor-bronze drawn wires and is taken from *Engineering*.

Description of Wire	Tensile Strength	Relative Conductivity
Pure Copper	39,827 Lbs. per sq. in.	100 per cent.
Silicon Bronze (telegraph)	41,696 " " " "	96 "
Silicon Bronze (telephone).....	108,080 " " " "	34 "
Phosphor Bronze (telephone)....	102,390 " " " "	26 "

FIG. 288.

ALLOYS; SOLDERS, BEARING METAL AND OTHER WELL KNOWN ALLOYS

291. Solders. Common Solder. Common solder is an alloy of equal parts of tin and lead. Fine solder contains 2 parts of tin to 1 of lead, while cheap solder contains 2 parts of lead to 1 of tin. These solders fuse at a temperature of about 370° F.

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Common Pewter. Common pewter contains 4 parts of lead to 1 of tin.

Gold Solder. Gold solder contains 14 parts of gold, 6 parts of silver, and 4 of copper.

Silver Solder. Silver solder contains 70 parts of yellow brass, 11½ parts of tin and 7 parts of zinc.

German Silver Solder. German silver solder contains 38 parts of copper, 54 of zinc and 8 of nickel.

292. Bearing Metal Alloys — Babbitt Metal. The well-known Babbitt metal contains approximately 50 parts of tin, 2 parts of copper and 4 parts of antimony. An excellent white metal alloy contains 55 parts of tin, 18 of antimony, 23½ of lead and 3½ of copper. The principal constituents of most bearing metals are copper, tin, lead, zinc, antimony, iron and aluminum.

293. Composition of 24 Bearing Metal Alloys. The table on page 49 (Fig. 293) gives the constituents of 24 of the most important bearing metals as analyzed in the Pennsylvania Railroad laboratory at Altoona:

294. Gurley's Bronze. Gurley's bronze is used for the frame work of engineer's transits, etc., and is composed, according to W. J. Keep, of 16 parts of copper, 1 of tin, 1 of zinc, ½ of lead, and has a tensile strength of 41,000 pounds.

295. German Silver. German silver is an alloy containing about 51.1 copper, 13.8 nickel, 3.2 tin and 31.9 zinc.

296. Aluminum Bronze. Aluminum bronze, an alloy of 90% copper and 10% aluminum, produces a remarkably tenacious metal, with a tensile strength varying from 75,000 to 90,000 pounds per square inch, with from 4% to 14% elongation.

297. Manganese Bronze. Manganese bronze is in reality a manganese brass, for zinc, instead of tin, is the chief element added to the copper.

The manganese existing in these alloys extends from a trace up to 5%; manganese may be mixed with copper to give a metal that may be forged. Its chief use, on account of its strength and ductility, is for propeller blade castings, although sheets of manganese bronze are used to a large extent, for mining screens, on account of their non-corrosive qualities.

Manganese bronze has a tensile strength of about 60,000 pounds per square inch; when rolled, however, its tensile strength reaches from 95,000 to 106,000 pounds per square inch. Many

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of the manganese bronzes on the market contain no manganese whatever.

298. Pewter and Type Metal. Pewter is an alloy containing copper, tin and antimony. A hard pewter is composed of 2 parts of copper, 96 of tin, and 8 of antimony; should the copper be increased a softer pewter would result. Common pewter contains 4 parts of lead to 1 part of tin.

Type metal is an alloy containing from 4 to 5 parts of lead to 1 of antimony.

299. Fusible Alloys. Bismuth is the chief element which gives the fusible alloys their low melting-point. Fusible alloys can be made by various compositions of lead, tin, bismuth and sometimes cadmium, with a melting-point of from 149° to 475° F. An alloy of 1 part lead, 3 parts tin, and 5 parts bismuth melts at 212° F. Alloys of bismuth have been used for making fusible plugs for boilers, but according to Kent, it is found that they are altered by the continued action of heat so that one cannot rely upon them to melt at the proper temperature.

Pure Banca tin is used by the United States Government for fusible plugs.

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ANALYSIS OF BEARING METAL ALLOYS

Metal	Copper	Tin	Lead	Zinc	Antimony	Iron
Carbon Bronze	75.47	9.72	14.57	—	—	—[2]
Cornish Bronze	77.83	9.60	12.40	trace	—	trace[3]
Tobin Bronze	59.00	2.16	0.31	38.40	—	0.11
Graney Bronze	75.80	9.20	15.06	—	—	—
Damascus Bronze	76.41	10.60	12.52	—	—	—
Manganese Bronze	90.52	9.58	—	—	—	—[5]
Harrington Bronze	55.73	0.97	—	42.67	—	0.68
Phosphor Bronze	79.17	10.22	9.61	—	—	—[7]
Carmelia Metal	70.20	4.25	14.75	10.20	—	0.55
White Metal	—	—	87.92	—	12.08	—
Delta Metal	92.39	2.37	5.10	—	—	0.07
Magnolia Metal	trace	—	83.55	trace	16.45	trace[4]
Ajax Metal	81.24	10.98	7.27	—	—	—[6]
Car-box Metal	—	—	84.33	trace	14.38	0.61
Ex. B. Metal	76.80	8.00	15.00	—	—	—[8]
Anti-friction Metal (No. 1)	1.60	98.13	—	—	—	trace
Anti-friction Metal (No. 2)	—	—	88.32	—	11.93	—
Salgee Anti-friction	4.01	9.91	1.15	87.57	—	—
American Anti-friction	—	—	78.44	0.98	19.60	0.65
Car-Brass Lining	—	trace	84.87	—	15.10	—
Graphite Bearing Metal	—	14.38	67.73	—	16.73	?[1]
Antimonial Lead	—	—	80.69	—	18.83	—
Hard Lead	—	—	94.40	—	6.03	—

Other Constituents:

[1] No graphite.
[2] Possible trace of carbon.
[3] Trace of phosphorus.
[4] (Torrey says this metal always contains tin.) Possible trace of bismuth.
[5] No manganese.
[6] Phosphorus or arsenic. 0.37.
[7] Phosphorus. 0.94.
[8] Phosphorus. 0.20.

FIG. 293.

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CHAPTER III

FRICTION, LUBRICANTS AND LUBRICATION

Friction and Lost Work

311. Friction. The surface of every solid, no matter how highly polished, on being observed through a microscope, has in it little elevations and depressions. When two surfaces are placed together the elevations of one tend to fill the depressions of the other and thus offer resistance to movement; it is this resistance that is termed friction. The work of smoothing or breaking off the interlocking points produces heat.

Friction is detrimental for the reasons: (1) that it takes power, (2) produces heat, (3) produces wear, and (4) is the cause of much trouble, the trouble arising in most cases from the increase in temperature and ensuing expansion. The only difference, then, that may exist between a bearing that gives trouble and one that does not may be in its conduction, rather than its production, of heat. The amount of power consumed in overcoming friction is astonishing to one unfamiliar with the subject and is estimated by various authorities to be from 40% to 80% of the fuel consumed.

312. Friction Reduction. If we interpose between two surfaces a film of oil, we discover that though they slide more easily they still offer some resistance to movement. This thin film of oil holds the surfaces apart, lifting the irregularities of the one free from those of the other, the remaining friction being that in the oil itself, there being no friction here of metal on metal, because they are not in contact. Examining the conditions which obtain in the ordinary bearing in operation, we find that the oil next the shaft moves with it while that on the bearing moves very slowly. The slower moving portion of the film has a retarding effect on the faster-moving portion and thus produces friction in the oil itself. Grossman discussing these conditions states that: "Different parts of the same lubricating layer, moving

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at different speeds, produce relative movements which result in friction in the lubricant itself. Movement of the solid surfaces over the slower moving fluid particles produces friction between the solid and the liquid bodies, and consequently the frictional resistance of well lubricated solid bodies consists of the sum of the frictional resistance between the fluid and the solid bodies and between the particles of the fluid itself."

It is clear from this, even to the veriest novice, that the thinner the oil the less internal friction it possesses and *vice versa*. The thinner the oil, however, the less ability it has of sustaining pressure, it being easily forced from the bearings under conditions of great pressure and high speed; while with the heavier oils of sufficient body to hold the surfaces apart, we have the greater internal friction. The temperature of a given oil, too, has much to do with its internal friction, for upon heating oils become thin and watery, and at still higher temperatures, on a surface where, when cold, we would expect oil to flow in a thin layer, we discover it to collect into minute globules which fly from the surface. For this reason it will be surmised that where excessive temperatures obtain, a solid lubricant such as graphite, talc, etc., must be used.

313. Laws of Friction. From the foregoing paragraphs we conclude, as Professor Thurston points out, that where mixed friction (friction of metals and friction of oil) occurs, as is the case under ordinary conditions of lubrication, its laws approximate those of solid friction as the bearing is run dry, and those of fluid friction as it is flooded with oil. Between these two extremes, solid and fluid friction, our coefficient of friction for a given condition must lie.

314. Coefficient of Friction. The coefficient of friction of a body is the ratio of a force, required to slide it along a horizontal plane surface, to its weight. If a body of weight W is made to slide on a horizontal plane surface by a force F which pushes it along with an uniform motion, the ratio $\frac{F}{W}$ is called the coefficient of friction. It is equivalent to the tangent of the angle of repose, which in turn is the angle of inclination to the horizontal of an inclined plane on which the body will just overcome its tendency to slide. This angle is generally designated by θ and the coefficient by f.

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If we represent the vertically acting force of gravity by the line *ab* (Fig. 314), its effect in holding the body against the plane will be proportional to the line *bc*, and its effect in sliding the body down the plane will be proportional to the line *ac*, each of these lines being drawn in the direction in which its representative force acts.

The quotient of the force tending to slide the body by the pressure between the sliding surfaces would be represented by $\frac{ac}{bc}$. Now *ac* is the sine of the angle at *b*, and *bc* is its cosine, and the quotient of the sine divided by the cosine is the tangent.

Since the angle at *a* is common to both triangles, *abc* and *abd*,

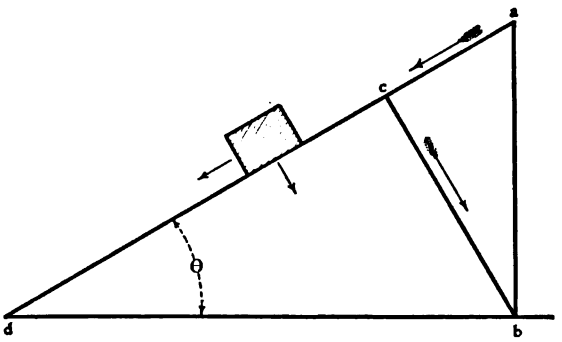

FIG. 314.

and both have a right angle, the remaining angles at *b* and *d*, respectively, must be similar, and what is true of the angle at *b* is true of that at *d* or that of the plane.

315. Solid Friction. With unlubricated solids sliding on one another *f* is practically a constant, dependent upon the nature of these surfaces, but independent of the area of contact of the pressure between the surfaces, and the velocity of rubbing.

316. Fluid Friction. Thurston gives the following laws of fluid friction: For all fluids, whether liquid or gaseous, the resistance is: (1) independent of the pressure between the masses in contact; (2) directly proportional to the area of rubbing surface; (3) proportional to the square of the relative velocity at moderate and high speeds and to the velocity nearly at low speeds; (4) independent of the nature of the surfaces of the solid against which the stream may flow, but dependent to some extent

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upon their degree of roughness; (5) proportional to the density of the fluid and related in some way to its viscosity.

As has been previously stated it is somewhere between the two extremes, the solid and liquid friction, that we must look for our coefficient for any given bearing.

Lubricants in General

321. The Function of Lubricants. Lubricants are used primarily to reduce friction; however, in the machine shop, when used in connection with cutting tools, they perform another important function, that of dissipating the heat generated in making the cut. When used in this latter connection it is true that, while heat dissipation is the main function, the advantage as a lubricant must not be overlooked, and it is for this reason that lard oil is one of the best cutting oils.

322. The Selection of Lubricants. So important is the selection of a lubricant for a given purpose that the profit or loss in a given manufacturing plant may depend upon it. A change of lubricant in one of the great cotton mills of Massachusetts effected a saving of 8½% of the coal, with an increase in the output of 2%. It is for this reason that scientific investigation and laboratory tests should precede the selection of a lubricant for a given condition. Any of the great oil-refineries now gladly furnish certificates guaranteeing the physical qualities of their various brands of oils, so that the laboratory examination of oils from reputable concerns may be dispensed with unless adulteration is suspected, leaving only the trial of the various oils to the purchaser. These merchants, and for that matter the manufacturers of solid lubricants as well, gladly assist in aiding their clients in such investigation by furnishing technical experts to supervise the tests.

Oil Compounds and Adulterations

331. Composition of Oils. It has been found by experiment that the best oil for lubricating bearings and other rubbing surfaces is invariably a pure mineral oil devoid of any vegetable or animal fat. The various factors, however, such as conditions of excessive pressure, speed, moisture, heat, cold and cost have led to the numerous brands which are usually mineral oils com-

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pounded with animal, vegetable and other ingredients to meet the various test requirements.

332. Vegetable Oils. Vegetable oils possess few or no lubricating qualities of practical value, oxidize at comparatively low temperatures and have a disposition to become thick and gummy.

333. Animal Oils. Animal oils, or carbohydrates, likewise tend to thicken and become gummy under the influence of heat and wear, and develop an objectionable acid which is sure to attack the metals with disastrous results.

334. Paraffine. Paraffine possesses few or no lubricating qualities and, aside from the production of a smooth surface, it is a resistant and retards the viscous action of an oil. It is used chiefly because it does not oxidize or evaporate readily.

335. Wool Fat. Wool fat (degras), a common adulteration in cheap cylinder oils, is used to cut the gummy ingredients and to secure a better cold test. Its presence in an oil generally causes a thick deposit at the bottom of the barrel and results in the same charred deposit in the cylinder that occurs from the use of lump tallow.

336. Objectionable Features. The presence of vegetable or animal oils, paraffine, resin, etc., tends to make an oil sticky and gummy, not only increasing the friction, but also rendering it efficient in the collection and accumulation of dirt. If it be necessary to compound an oil, pure, refined, acidless tallow oil, or pure, sweet, winter-strained lard oil should always be used.

Lubricating Oils

341. Qualifications of a Good Lubricant. Continued investigation and recent research indicate that the qualifications of a good lubricant are: (1) A minimum coefficient of friction—that which in bath lubrication most nearly approximates fluid friction. (2) Sufficient body to prevent the surfaces to which it is applied from coming in contact with each other under maximum pressure. (3) A maximum fluidity consistent with the body required. (4) A maximum conduction of heat. (5) A high temperature of decomposition, that is, high flash and burning points. (6) A freedom from corrosive acids of either mineral or animal origin. (7) A freedom from all materials which tend to produce oxidization or gumming. (8) Its value, determined from the cost of

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consumption, cost of coal spent to overcome friction, and cost due to metallic wear.

342. Oil Tests. An examination, in the determination of the above qualifications of the physical and chemical qualities of an oil, should proceed, according to Professor Stillman, in the following order: (1) Identification of the oil, whether a simple mineral oil or animal oil, or a mixture; (2) density; (3) viscosity; (4) flash-point; (5) burning-point — fire test; (6) acidity; (7) coefficient of friction, and (8) cold test.

343. Density of Gravity Test. The density or gravity test is made by means of an hydrometer and is an indication of viscosity, for the specific gravity of a particular petroleum oil increases as the viscosity increases.

344. Viscosity or Fluidity Test. The viscosity or fluidity of an oil is determined by a viscosimeter and is usually expressed in the seconds of time in which a given quantity of oil will flow through an orifice, at a stated temperature. It is evident that, within the limits, the lower the viscosity of an oil (without too near an approach to metallic contact of the rubbing surfaces) the lower will be the coefficient of friction. From this we note that each bearing would probably require an oil of a different viscosity, or that a slight change in a particular bearing would again change the requirements.

345. Flash or Fire Test. The object of the flash and fire test in most instances is to insure the prevention of fire that might occur from the use of an oil giving off inflammable vapors; the higher the temperature under which the oil must work, the higher the fire test, so that it will not decompose or volatilize; though still, in the case of a cylinder oil, atomizing readily. Too high a fire test gives an oil that does not atomize readily enough to reach all the parts of the cylinder with the steam. The lowest ordinary fire test permissible is 300°. The flashing and burning points are determined by heating the oil in an open vessel, not less than 12° per minute, and applying the test flame every few degrees.

346. Acidity Test. The object of the acidity test, as its name indicates, is the determination of the presence of injurious acids.

347. Cold Test. The cold test is the determination of the temperature at which the oil will congeal, and must always be well below the conditions under which the oil operates. It is

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made by having an ounce of oil in a four-ounce sample bottle with a thermometer suspended in the oil, and exposing this to a freezing mixture of ice and salt; when the oil has become hard the bottle is removed from the freezing mixture and the frozen oil allowed to soften, being stirred and thoroughly mixed at the same time by means of the thermometer, until the mass will run from one end of the bottle to the other. The reading of the thermometer, when this is the case, is regarded as the cold test. This test is made for the purpose of determining whether or not the oil will feed freely without clogging through the lubricators.

348. Oil Inspection. When it is necessary on account of the moisture, as in the case of a cylinder oil, to compound the straight mineral oil with a little animal oil, none but refined, acidless tallow oil should be used.

The presence of paraffine — always highly objectionable — may be discovered by placing a bottle of oil on ice for fifteen minutes; if the oil becomes cloudy, it is an indication of paraffine and should be rejected without further investigation.

The opalescent green tinge on engine oils is due to their adulteration with either kerosene or some lighter hydrocarbon which is not a lubricant and which is easily volatilized. All lubricating oils should be entirely free from grit, the presence of which may be discovered by the use of a magnifying glass.

349. Volatile Oils. Coal oil, otherwise known as kerosene, refined petroleum oil, and mineral sperm oil are among the most fluid oils and are excellent for cleaning bearings. The vapors from such volatile oils as benzine, naphtha and turpentine, when mixed with air, form a dangerous explosive. Considerable care, therefore, should be exercised in their use, which in the machine shop is generally for cleaning purposes.

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Oil Specifications

351. Table of Chemical and Physical Properties of 12 Ordinary Lubricating Oils.

Kind of Oil	Use and Adaptation	Gravity	Cold Test	Flash Test	Fire Test	Viscosity at 70°
High Pressure Cylinder Oil.....	For steam cylinders using dry steam at pressures from 110 to 210 lbs.	25° to 24.5°	30°	600° to 610°	645° to 660°	175 to 205
General Cylinder Oil	For steam cylinders using dry steam at 75 to 100 lbs. For air compressor cylinders when made from steam refined mineral stock and when viscosity is 200.	26° to 25.5°	30°	550° to 585°	600° to 630°	180 to 190
Wet Cylinder Oil... *Remark 1*	For use where the steam is moist, especially in compound and triple-expansion engines.	25.8° to 25.3°	30°	560° to 585°	600° to 630°	150 to 185
Gas Engine Cylinder Oil..... *Remark 2*	For gas engine cylinders. Neutral mineral oil compounded with an insoluble soap to give body.	26.5°	30°	320°	350°	300
Automobile Gas Engine Oil *Remark 3*	For automobile gas engines and similar work.	29.5°	30°	430°	485°	195
Heavy Engine and Machinery Oils...	For heavy slides and bearings, shafting and horizontal surfaces.	30.5° to 29.5°	30°	400°	440° to 450°	170 to 195
General Engine and Machine Oils	For high-speed dynamos and machines.	30.8° to 30°	30°	400° to 420°	450° to 470°	175 to 190

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351. Table of Chemical Properties (*continued*).

Kind of Oil	Use and Adaptation	Gravity	Cold Test	Flash Test	Fire Test	Viscosity at 70°
Fine and Light Machine Oils.....	For fine work from printing presses to sewing machines and typewriter oils. With a cold test of 25° to 28° and a viscosity of 140° this makes an excellent spindle oil.	32.5° to 30.2°	30°	400°	440°	110 to 160
Cutting and Dissipating Oils..... *Remark 4*	For cutting tools, screw cutting and similar work.	27° to 23°	30°	410° to 420°	475° to 480°	175 to 210
Refrigerating Oils..	For ice machinery.	30.2°	0°	200°	225°	165
Wet Service and Marine Oils..... *Remark 5*	For marine service or where a great deal of moisture must be handled.	28°	30°	430°	475°	230
Greases	They are used in special work and for heavy pressures moving at slow velocities.					

Remark 1. May contain not over 2% to 6% of refined acidless tallow oil in the high-pressure oils, and not over 6% to 12% in the low-pressure oils.

Remark 2. The reason for using an insoluble soap such as oleate of aluminum is that it is impossible to decompose the soap with a high heat — the soap, although not a lubricant, is a vehicle for carrying some oil.

Remark 3. Owing to a lack of body this oil will not interfere with the sparking by depositing carbon on the platinum point.

Remark 4. Sometimes contains as much as 40% of lard oil. A pure strained lard oil, though more expensive, is probably superior to any mixture for this purpose.

Remark 5. May contain 30% to 40% of pure strained lard oil.

FIG. 351.

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352. Lubricant Friction. In a table of the comparative friction of different lubricants under the same circumstances, temperature 90°, oil bath, Tower gives the following:

Sperm Oil	100%	Lard Oil	135%
Rape Oil	106%	Olive Oil	135%
Mineral Oil	129%	Mineral Grease	217%

353. Lubricant Application. The following table, Fig. 353, prepared from various sources, is intended to give some idea of the comparative values of the various methods of lubrication; a value of 1 being given to a method whose coefficient of friction is .01.

Method of Lubrication	Coefficient of Friction	Comparative Value
Oil Bath	.00139	7.19
Pad under Bearing	.009	1.11
Siphon Lubricator	.0098	1.02
Oil Cups, Restricted Rates of Feed	.01 to .012	1 to .83
Intermittent Application	.01 to —	1 to —

FIG. 353.

SOLID LUBRICANTS

361. Use of Solid Lubricants. In many instances the use of some form of solid lubricant will be found advantageous, especially where heavy pressures are used and for such troubles as binding, heating and grunting, where oil by its very nature would fly from or be forced out of the bearings.

362. Graphite. Pure, flaked graphite is the best solid lubricant known; it is generally mixed in some oil which provides a means of getting it to the rubbing parts. Its manufacturers make the following claims regarding it: (1) It effects a saving of 20% to 90% in oil or grease; (2) it increases the efficiency of other lubricants of the best quality many hundred per cent.; (3) it is incomparable in breaking in new engines and machines, and (4) it is the only perfect lubricant for gas-engine cylinders. This statement should be questioned as many users of small engines report trouble with deposits of graphite on the spark terminals. To obtain these results the graphite should be entirely free from any grit or foreign matter and should be water-

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dressed and air-floated. Furthermore graphite is entirely inert and not affected by heat, cold, steam, acid or any known chemical; it largely increases the lubricating values of any oil or grease and may be mixed in water, oil or grease, or used dry according to the requirements of the conditions.

363. Talc. Talc, sometimes called soap stone, in the form of powder and mixed with a heavy oil, grease or soap, is occasionally used on surfaces of wood, working against either wood or iron.

Heat Dissipating Lubricants

371. Twofold Action of Heat-dissipating Lubricants. The action of cutting or heat-dissipating lubricants is generally twofold; not only do they reduce the friction between the chip and the tool, but when used in sufficient quantities they successfully dissipate the heat generated, thus increasing the output and the life of the cutting edge in some instances as much as 40%.

372. Heat-dissipating Mixtures. Lard or sperm oil is the best lubricant for cutting wrought iron and steel, though many of the cutting oils on the market give efficient service.

Soda water, a mixture of one part sal soda (sodium carbonate) with twenty parts of water, forms an excellent lubricant for this same purpose, and one that will not rust.

Soft-soap mixed with enough water to make it flow freely is sometimes used, while water alone gives the peculiarly bright surface which is known as a "water cut."

373. Dry Cuts. Cast iron, copper and brass are generally cut dry. Babbitt metal is usually cut dry, though a copious supply of kerosene will produce excellent results.

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CHAPTER IV

CUTTING TOOLS

Discussion

411. Governing Conditions. In general, all metal-cutting tools are modifications of the wedge, both in design and operation. They should always be as sharp as the conditions will allow. In discussing the metal-working tools used in machines there are four governing conditions to be considered: (1) The keenness of the tool; (2) the strength and durability of the cutting edge; (3) the relative position of the tool and the work, and (4) the shape of the tool and the material to be cut.

412. The Keenness of the Tool. Since the action of the tool is that of a wedge, the more acute the angle of keenness — k in the figures — ignoring all other conditions, the less the resistance offered to the removal of the chip.

413. The Strength and Durability of the Cutting Edge. The strength and durability of the cutting edge is as important a factor as that of keenness. Upon it depends the amount of stock that can be removed at a cut, the feed and the interval between grindings. To obtain greater durability and strength, we give additional support to the cutting edge by decreasing both the clearance, c, and the top rake, tr; these angles depending upon the material to be cut and the position of the tool.

414. The Relative Position of the Tool and Work. It is evident that when the cutting edge is tangent to the work, the least possible resistance is offered in removing the chip and that this is its ideal position (Fig. 414a). Owing to the fact that the point of tangency changes with every chip, it is necessary to set the tool somewhat lower than this position. Considering the tool alone, without any reference to its relation to the work, we will draw AB parallel to the base of the tool and D perpendicular to AB, both through the cutting edge O of the tool (Fig 414b). The angle tr is called top rake; the angle c clearance; while keen-

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ness refers to the angle *k*. By an inspection of Fig. 414*c* it will be found that the angles of clearance and top rake change with every position of the tool.

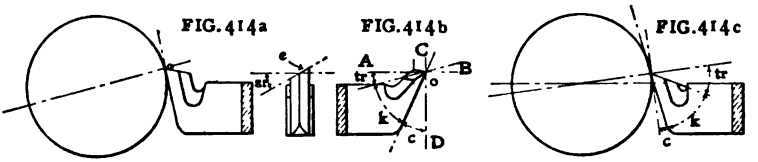

FIG. 414*a*, *b*, *c*.

415. The Shape of the Tool and the Material to be Cut. The material to be cut determines the shape of the tool and its effective angles of clearance, keenness and top rake. The conditions governing these angles, in turn, depend upon (*a*) the kind of metal to be cut; (*b*) the hardness of the metal; (*c*) the character of the cut, roughing or finishing — and (*d*) the manner of presenting the tool to the work. As a general statement, the angle of keenness is more acute for the soft metals, such as wrought iron and mild steel — except where the metals have a tendency to draw in the tool — than for the harder ones such as chilled cast iron and tool steel. Copper and its various alloys such as brass, bronze, etc., have a tendency to draw in the tool, and for working these alloys the angles of the tool are made very blunt; in fact, negative rake is often given.

In the deep coarse-fed roughing cuts, the cutting edge is at *e*, (Fig. 414*b*), and the keenness is obtained from the side rake, *sr;* while, in the light, finer fed finishing cuts, characteristic in small work, the cutting edge is at *o*, and keenness is obtained from the top rake. This statement also has reference to the manner of presenting the tool to the work.

Feeds and Speeds

421. The Surfaces of Metals and the Character of the Chip. The surface of most metals, and especially that of castings, is usually much harder than the interior. In wrought metals, such as machinery steel, etc., this hardness, ofttimes negligible, is due to the direct action of the rolls on the surface; in castings this hardness is due to the chilling action of the surface of the mold. For this reason the first roughing cut should go entirely below

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or beneath this hard surface film; otherwise the tool heats and is rapidly dulled.

The proper adjustment of the tool is had when it produces a clean, smooth, rather tightly curled chip, as contrasted with one that is rough and crumbling. According to condition 3 this brings the cutting edge of a properly ground tool slightly above the line of centers.

422. General Rules Relative to Feeds and Speeds. Practice has shown that metal can be removed more rapidly by taking heavy cuts at relatively low speeds; the greater the reduction in diameter the finer the feed. In general, this rule applies to roughing cuts; to produce smooth, finished surfaces, however, a light cut at a fast speed and fine feed is used. The feed and speed used in any case are governed by the following limitations: (1) The strength of the tool with reference to breakage — to avoid breakage see that the tool is properly adjusted and never start the machine backward. (2) The wearing of the cutting edge. To avoid excessive wear sharpen and set the tool so as to cleave the chip off rather than to pulverize it. (3) The heating and consequent loss of temper of the cutting edge. To obviate this difficulty the tool should be kept sharp; the trying to push off the stock with a dull edge consumes more time and tool than the grinding necessary to keep it sharp. (4) A weak machine drive. See that the driving belt is tight — not loose enough to slip — and on the proper pulley. (5) Lack of stability in the work. A weak piece of work, so weak as to spring, must be either humored or supported.

The difficulty of recommending a definite feed and speed per minute in any case will be seen upon referring to the discussion in the abstracts of the papers on this subject which appear in Sections 424, 425, 426 and 427.

Precautions. The cutting edge of the tool should be as near to the tool post as is possible without interference between the dog and the carriage.

In order to reduce the friction on the dead center, always feed toward the live center.

Never reverse the feed or throw in the back gears while the machine is running.

423. Remarks Concerning the Author's Investigations. In the more recent experiments, especially in those pertaining to high-

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speed tool steels, a great number of valuable data have been compiled and practice long considered excellent becomes obsolete in the light of these investigations. The following matter abstracted from an article on "Feeds and Speeds," published by the author in the *American Machinist*, Dec. 25, 1902, though in minor respects superseded by more recent data, is given, however, as being the best available for a general presentation of the subject to the student. The article, written before the general use of high-speed tool steels, deals necessarily with ordinary tool steels, *i.e.* those varying from 70- to 90-point carbon and tempered in the ordinary manner.

For data relative to the size of chip, speed, feed and the horse-power required to remove it, the student is referred to Chapter 20, "Motor Drives," etc., Section 2054.

424. Author's Research.— Ordinary Low-speed Tool Steels. From the pages of such technical and trade periodicals as the *American Machinist*, *Machinery*, etc., and from those of the excellent catalogs which it is the habit of our machine builders to produce, data relative, generally, to the maximum feeds and speeds were separated and tabulated. This was done with special reference to the determining of the best feed and speed to be used in the removal of a maximum amount of stock, screw-machine practice being used as one of the guide posts in our journey of discovery.

To discover and ascertain the nature of any existing law was the next step. The data relative to each machining process for a given material were transferred to squared paper, where the curve was plotted; the ordinates representing speeds, the abscissas the feeds. Brass, being the softest material, was first plotted; its values for turning operations were plotted for the four following reductions: (1) $\frac{1}{16}$ reduction in the diameter, ordinary practice and small reductions being here included; (2) $\frac{1}{8}$ reduction of diameter; (3) $\frac{1}{4}$ reduction of diameter; (4) $\frac{1}{2}$ reduction in diameter. The average feed used for small reductions and rapid cutting was found to be about 20 per inch; while that for $\frac{1}{2}$ and similar large reductions was about 100 per inch. The feeds used for $\frac{1}{4}$ and $\frac{1}{8}$ reductions were found to be grouped near what would be the second and third terms of a geometrical progression between these two values.

In plotting our final diagram, the feeds corresponding to

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reductions of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$ and $\frac{1}{2}$ were made 20, 34.2, 58.48 and 100 respectively; *i.e.* they were arranged in geometrical progression. To these special ordinates were transferred the data for such milling, drilling and planing operations as were made with what might be termed correspondingly heavy cuts; the word reduction, in reference to any other operation save that of turning, being of course a misnomer. After plotting the curves for brass, the task of plotting the curves for cast iron, wrought iron, machinery steel and tool steel proved comparatively easy.

A careful examination of these several plottings seems to reveal the important fact that, not only did the lines for the several operations on the same material radiate from an apparently common origin, but that the lines for these operations for all the materials did likewise; that is, they justified one in assuming that they had a common origin. This being the case, a single plotting was made, the lines being transferred from the four sheets, and the values plotted from a common origin. The equations for these curves formed a step deemed necessary for the compilation of an accurate table of maximum feeds and speeds for these materials. These equations were corrected and simplified without materially altering their values.

CORRECTED EQUATIONS

	Brass	Cast Iron	Wrought Iron and Mach. Steel	Tool Steel
Turning ..	$S = -\frac{3}{4} F + 106$	$S = -\frac{5}{12} F + 66$	$S = -\frac{1}{3} F + 53$	$S = -\frac{5}{24} F + 33$
Milling ...	$S = -\frac{1}{2} F + 80$	$S = -\frac{5}{16} F + 50$	$S = -\frac{1}{4} F + 40$	$S = -\frac{5}{32} F + 25$
Drilling ..	$S = -\frac{2}{5} F + 64$	$S = -\frac{1}{4} F + 39$	$S = -\frac{1}{5} F + 32$	$S = -\frac{1}{8} F + 20$
Planing ..	$S = -\frac{1}{3} F + 53$	$S = -\frac{5}{24} F + 33$	$S = -\frac{1}{6} F + 27$	$S = -\frac{5}{48} F + 17$

A careful examination of these corrected equations, with due consideration as to the manner in which they were obtained, will justify us in stating that another important fact is revealed, namely, that the various operations possess values and relations irrespective of the materials on which they were performed. To be more specific, assigning a value of unity to turning operations, we may say that the value for milling operations is $\frac{3}{4}$, drilling $\frac{2}{5}$, and planing $\frac{1}{2}$. Here are data that corroborate what we already know, namely, that the lathe is more efficient than any of our

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other machine tools; how much, is of course desirable information. We might say, too, that it behooves the intelligent designer or foreman to plan the greater part of his work for the lathe, leaving a minor part to be accomplished by the planer.

One more important fact, which may be deduced from the equations, is the relation which we find to exist between what we might call the working texture of the average materials used in our shops. He who has to do with the problems of cost reduction will welcome this and kindred data in reference to his stock materials. It was discovered that when the value of 16 was assigned to brass, cast iron had a value of 10, wrought iron and machinery steel 8 and tool steel a value of 5.

Turning our attention now to the diagrams, of which we have three, one containing the data for brass and tool steel (Fig. 424*a*) one for cast iron (Fig. 424*b*) and one for wrought iron and machinery steel (Fig. 424*c*), we find them to be, to a large extent, self-explanatory; however, a few words of explanation may prove of some assistance. The lines marked "Turning," "Milling," "Drilling" and "Planing" respectively give the best speed and feed values for a predetermined reduction. By the term "best" speed and feed values the author wishes to convey the idea that this is the speed and feed that will remove a maximum amount of material when due consideration is given to economy and the time required for changing and grinding the tools. These values, it must be remembered, are for materials of average texture and composition, special materials requiring, of course, special feeds and speeds. Assuming that we have a piece of cast iron 2″ in diameter which we wish to turn down to $1\frac{1}{4}$″ in diameter, that is, a $\frac{1}{8}$ reduction; having determined upon the reduction, $\frac{1}{8}$, we follow the line marked "turning" in the chart for cast iron to its intersection with our $\frac{1}{8}$ reduction lines; dropping vertically on this line, we read our feed, 34.2. Passing horizontally from the intersection to the right, we read the speed 52. Having now determined the speed in feet per minute, it is only necessary to determine the number of revolutions that will give to the piece this speed. Consulting the "Table of Revolutions for Given Diameters and Cutting Speeds" (Section 428), (Fig. 428), we find that our piece must make about 95 revolutions per minute. The table of "Cutting Speeds for Common Reductions" (Fig. 424*d*) gives the formulas and tabulated speeds as

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obtained from the charts, it being assumed that this is a more convenient form when seeking ordinary reductions.

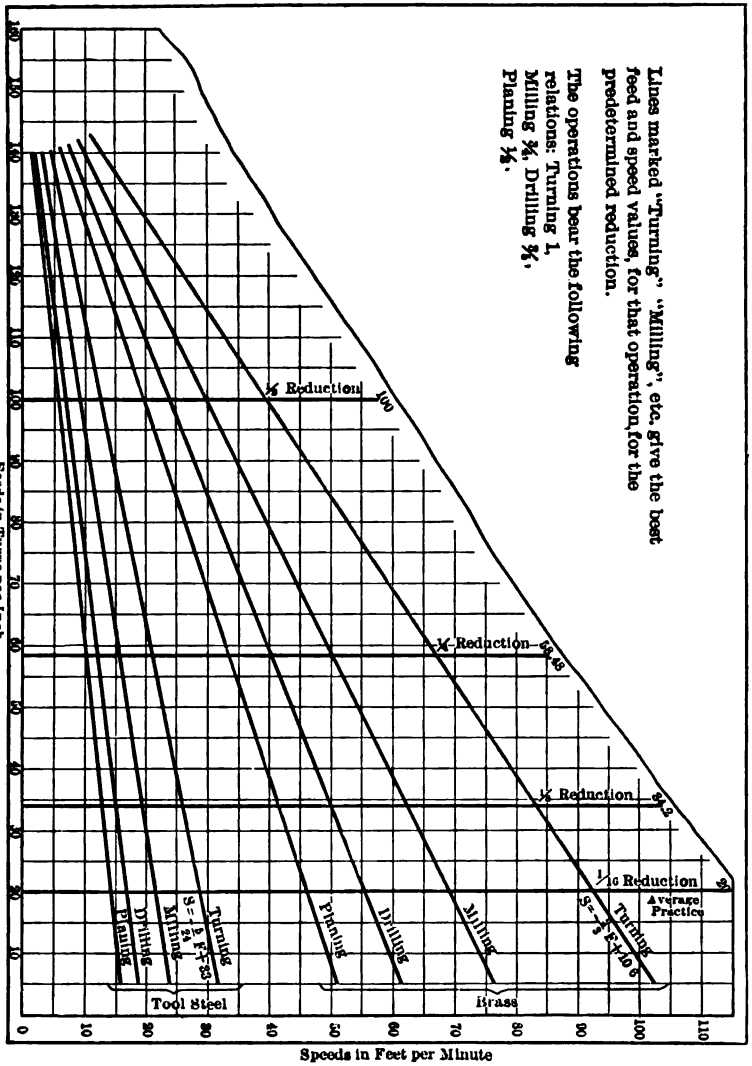
Lines marked "Turning", "Milling", etc. give the best feed and speed values, for that operation, for the predetermined reduction.
The operations bear the following relations: Turning 1, Milling ¾, Drilling ¾, Planing ⅓.
½ Reduction
¼ Reduction
⅛ Reduction
1/16 Reduction
Average Practice
Turning
Milling
Drilling
Planing
Brass
Tool Steel
Feeds in Turns per Inch
Speeds in Feet per Minute

FIG. 424a. — Feeds and Speeds for Brass and Tool Steel — Low Speed Steel.

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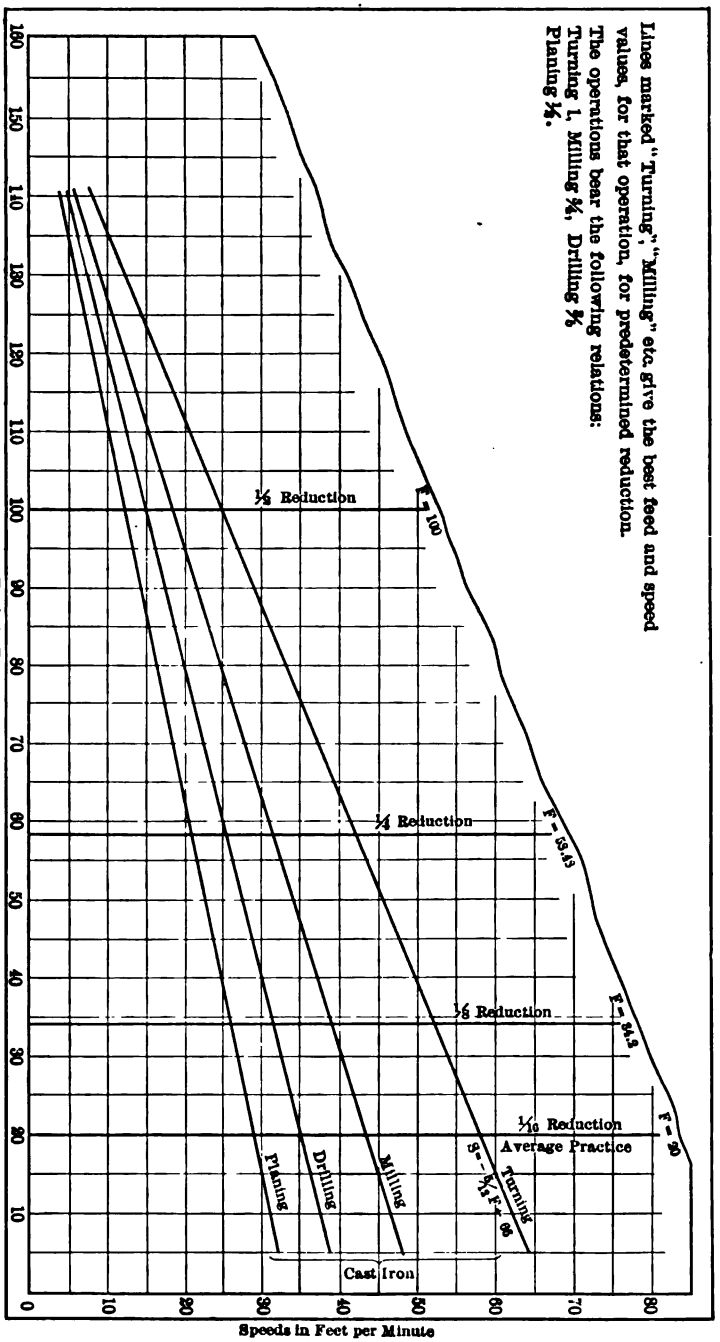
Lines marked "Turning," "Milling" etc. give the best feed and speed values, for that operation, for predetermined reduction.
The operations bear the following relations:
Turning 1, Milling ¾, Drilling ⅔
Planing ½.
⅛ Reduction
F = 100
¼ Reduction
F = 58.43
⅛ Reduction
F = 34.2
1/10 Reduction
Average Practice
F = 20
S = K/5 F^1.66
Turning
Milling
Drilling
Planing
Cast Iron
Feeds in Turns per Inch
Speeds in Feet per Minute
0 10 20 30 40 50 60 70 80
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160

FIG. 424b. — Feeds and Speeds for Cast Iron — Low Speed Steel.

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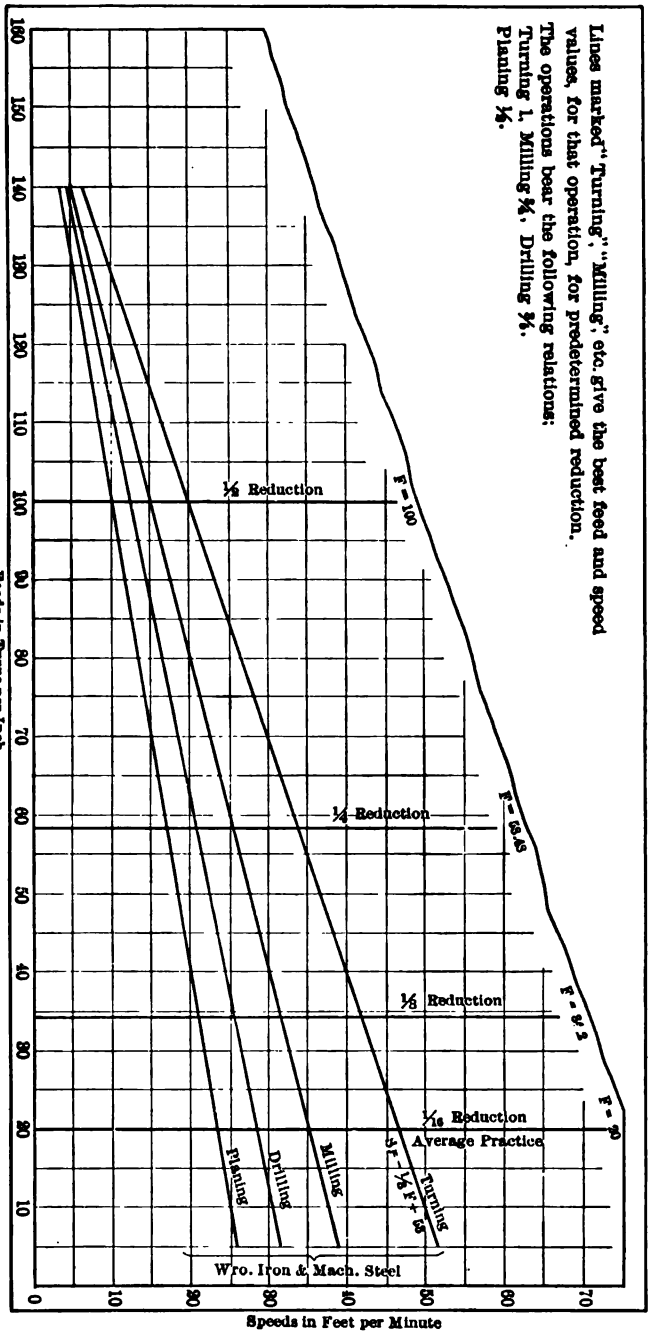

Fig. 424c. — Feeds and Speeds for Wrought Iron and Machinery Steel — Low Speed Steel.

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TABLE OF CUTTING SPEEDS FOR COMMON REDUCTIONS. LOW-SPEED STEELS

Speeds in Feet Per Minute

Operation	Formula	F = 20	F = 34.2	F = 58.48	F = 100
		$\frac{1}{16}$ reduction and average practice on light cuts	$\frac{1}{8}$ reduction	$\frac{1}{4}$ reduction	$\frac{1}{2}$ reduction
		Brass			
Turning	$S = -\frac{2}{3} F + 106$	93	83	67	39
Milling	$S = -\frac{1}{2} F + 80$	69	62	50	30
Drilling	$S = -\frac{2}{5} F + 64$	56	50	40	24
Planing	$S = -\frac{1}{3} F + 53$	46	42	34	20
		Cast Iron			
Turning	$S = -\frac{5}{12} F + 66$	58	52	42	25
Milling	$S = -\frac{5}{16} F + 50$	43	39	31	18
Drilling	$S = -\frac{1}{4} F + 39$	35	31	25	15
Planing	$S = -\frac{5}{24} F + 33$	29	26	21	12
		Wrought Iron and Machinery Steel			
Turning	$S = -\frac{1}{3} F + 53$	46	42	34	20
Milling	$S = -\frac{1}{4} F + 40$	35	31	25	15
Drilling	$S = -\frac{1}{5} F + 32$	28	25	20	12
Planing	$S = -\frac{1}{6} F + 27$	23	21	17	10
		Tool Steel			
Turning	$S = -\frac{5}{24} F + 33$	29	26	21	12
Milling	$S = -\frac{5}{32} F + 25$	22	20	16	9
Drilling	$S = -\frac{1}{8} F + 20$	17	16	13	7
Planing	$S = -\frac{5}{48} F + 17$	14	13	10	6

FIG. 424*d*.

425. Abstract of Professor Nicholson's Investigations. Dr. J. T. Nicholson, in a valuable paper read before the American Society Mechanical Engineers, June, 1904, recording exhaustive experiments with a lathe tool dynamometer, arrives at the following conclusions: In outlining the series of tests, he says: "For

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both cast iron and steel it was the intention to make trials with each of four different traverses (feeds), $\frac{1}{16}''$, $\frac{1}{8}''$, $\frac{1}{4}''$ and $\frac{3}{8}''$ with four depths of cut for each traverse, $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{3}{8}''$ and $\frac{1}{2}''$. This scheme was carried out in the case of cast iron so far as was possible with the means available, for each of the four cutting angles of 45, 60, 75 and 90°."

Speaking in reference to his Table 2 recording the stresses obtained, in accordance with the above schedule, on cast iron with a speed of 25 feet per minute, he says:

(1) This plate indicates a somewhat lower stress (tons per square inch) for wide than for fine traverses (feeds), although this conclusion does not appear to hold in its entirety, especially for the keenest cutting angle used, 45°.

(2) For a given traverse the cutting force is simply proportional to the depth of the cut [for a contrary finding see Sections 426 and 427] or that the cutting stress is constant for a given width of traverse and a given tool angle.

(3) The variation of the cutting stress with the cutting angle is very marked. It varies by nearly 100% of its smallest value, which takes place in every case for a cutting angle of about 60°. However, this angle of minimum cutting force is by no means that of greatest durability. A cutting angle of 80° is that indicated as being best for shop use, and the cutting stress for this angle is about 75 tons per square inch.

Note. In a duration test of the different cutting angles on cast iron, with a cutting speed of 44 feet per minute, a cut $\frac{3}{16}''$ in depth and a traverse of $\frac{1}{16}''$, Professor Nicholson found that his experiments verified the "Manchester Report," which recommends a true cutting angle of 81°. He says (4) "Tools should therefore be ground for a maximum endurance in the cutting of cast iron in ordinary shop practices, so that their true cutting angles are about 81°, or if they are allowed 6° clearance for working on the level of lathe centers, they should have an included angle (angle of keenness) of 75°.

(5) The variation of the cutting stress with the traverse — speed 50 feet per minute — in the case of soft steel is somewhat complicated. For keen cutting angles (below 75°), fine traverses require less cutting force than wide ones; while for blunt-nosed tools (*i.e.* cutting angles greater than 75°) the reverse is the case, and the fine traverse cut requires the greater effort to

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remove. At a cutting angle of 75° the stress is the same whether the traverse be $\frac{1}{16}''$ or $\frac{1}{8}''$ and has the value of about 100 tons per square inch. It is curious to remark that this angle of 75° is also about the best angle for shop use as shown by the durability trials.

(6) With medium fluid pressed steel two series of endurance tests were made, one at 74 feet per minute and one at 73 feet per minute cutting speed; the cut in both cases being $\frac{1}{4}''$ deep and $\frac{1}{8}''$ wide. Taken altogether these tests seem to show that a cutting angle of about 70° (angle of keenness 65°) is that which will last the longest in rapid cutting; the plan angle of the cutting edge was 45° throughout.

426. Abstract of President Taylor's Investigations. (High-speed Steels.) The discoveries of Pres. F. W. Taylor and his associates are of such a character and magnitude as to render impossible any but an inadequate résumé. These investigations were presented before the American Society of Mechanical Engineers in December, 1906, and form a part of volume 28 of the Proceedings of that Society.

The paper deals with the problem under the following heads:

(1) *Action of the Tool and Its Wear in Cutting Metals.*

(2) *How Modern High-speed Tools Wear.*

(3) *How to Make and Record Experiments.*

(4) *Lip and Clearance Angles of Tools.* The important conclusions under this heading are:

(*a*) For standard shop tools to be ground by a trained grinder or on an automatic grinding machine, a clearance angle of 6° should be used for all classes of roughing work.

(*b*) In shops in which each machinist grinds his own tools a clearance angle of from 9° to 12° should be used.

For standard tools to be used in a machine shop for cutting metals of average quality: Tools for cutting cast iron and the harder steels beginning with a low limit of hardness, of about carbon 0.45%, say, with 100,000 pounds tensile strength and 18% stretch, should be ground with a clearance angle of 6°, back slope 8° and side slope 14°, giving a lip angle of 68°.

For cutting steels softer, say, than carbon 0.45%, having about 100,000 pounds tensile strength and 18% stretch, tools should be ground with a clearance angle of 6°, back slope of 8°, side slope of 22°, giving a lip angle of 61°.

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For shops in which chilled iron is cut a lip angle of from 86° to 90° should be used.

In shops where work is mainly upon steel as hard or harder than tire steel, tools should be ground with a clearance angle of 6°, back slope 5°, side slope 9°, giving a lip angle of 74°.

In shops working mainly upon extremely soft steels, say carbon 0.10% to 0.15%, it is probably economical to use tools with lip angles keener than 61°.

The most important consideration in choosing the lip angle is to make it sufficiently blunt to avoid the danger of crumbling or spalling at the cutting edge.

Tools ground with a lip angle of about 54 degrees cut softer qualities of steel, and also cast iron, with the least pressure of the chip upon the tool. The pressure upon the tool, however, is not the most important consideration in selecting the lip angle.

In choosing between side slope and back slope in order to grind a sufficiently acute lip angle, the following considerations, given in the order of their importance, call for a steep side slope and are opposed to a steep back slope:

(*a*) With side slope the tool can be ground many more times without weakening it.

(*b*) The chip runs off sideways and does not strike the tool-posts or clamps.

(*c*) The pressure of the chip tends to deflect the tool to one side and a steep side slope tends to correct this by bringing the resultant line of pressure within the base of the tool.

(*d*) Easier to feed.

The following consideration calls for at least a certain amount of back slope. An absence of back slope tends to push the tool and the work apart, and therefore to cause a slightly irregular finish and a slight variation in the size of the work.

(5) *Forging and Grinding Tools.* The important conclusions under this heading are:

The shapes into which tools are dressed and the ordinary methods of dressing them are highly uneconomical, mainly because they can be ground only a few times before requiring redressing.

The tool steel from which the tool is to be forged should be one and one half times as deep as it is wide.

To avoid the tendency of the tool to upset in the tool post

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under pressure of the cut, the cutting edge and the nose of the tool should be set well over to one side of the tool.

Tool builders should design lathes, boring mills, etc., with their tool posts set down lower than is customary below the center of the work.

In choosing the shape for dressing a tool, that shape should be given the preference in which the largest amount of work can be done for the smallest combined cost of forging and grinding.

Forging is much more expensive than grinding, therefore the tool should be designed so that it can be ground,

(*a*) the greatest number of times with a single dressing; and

(*b*) with the smallest cost each time it is ground.

The best method of dressing a tool is to turn its end up high above the body of the tool. Tools can be entirely dressed by this means in two heats.

The importance of carefully heating the tool for dressing.

Fire or heat cracks in tools are due to the following causes:

(*a*) Seams or internal cracks in bar of tool steel.

(*b*) Nicking or breaking the bar of tool steel while it is cold.

(*c*) Failing to turn the tool over and over while heating it for forging.

(*d*) Too rapid heating, particularly at the start, in a hot fire.

It is of great importance to properly adjust the amount of work to be done in the smith shop and on the grinding machine, in making the tool.

(*a*) Too much work is generally done in dressing tools to exact shape in the smith shop, particularly when automatic grinding machines are used.

(*b*) A limit gage should be used by the smith to properly regulate the proportion of smith work and grinding work in making the tool.

More tools are ruined in every machine shop *through overheating in grinding* than from any other cause.

The most important consideration is how to grind tools rapidly without overheating them.

To avoid overheating, a stream of water amounting to five gallons per minute should be thrown, preferably at a slow velocity, directly on the nose of the tool where it is in contact with the emery wheel.

To avoid overheating where tools are ground by hand or with

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an automatic tool grinder, the surface of the tool should never be allowed to fit closely against the surface of the grindstone. To prevent this, tools should be constantly moved or wobbled about during the operation of grinding.

To lessen the danger of overheating on the emery wheel and to promote rapid grinding, tools should be dressed so as to leave the smith shop with a clearance angle of about 20°, while 6° only is needed for cutting.

Flat surfaces upon tools tend far more than curved surfaces to heat tools in grinding.

Tools with keen lip angles (*i.e.* steep side slopes) are much more expensive to grind than blunt lip angles.

It is economical to use an automatic tool-grinding machine even in a small shop.

There is little economy in an automatic grinder for any shop unless standard shapes have been adopted for tools, and a large supply of tools is kept always on hand in a first-class tool-room so that tools of exactly the same shape can be ground in large batches or lots.

Corundum wheels made of a mixture of grit size No. 24 and size No. 30 are the most satisfactory for grinding ordinary shop tools.

In grinding flat surfaces skilful hand grinders invariably keep the tool wobbling about on the face of the grindstone in order to avoid heating.

(6) *Pressure of the Chip upon the Tool.* The most important conclusions arrived at on this subject are, for cast iron:

Total pressure of chip on tool in cutting cast iron, of the different qualities experimented upon by us, varies between the low limit of 35 tons (2000 pounds) per square inch, sectional area of chip, for soft cast iron when a coarse feed is used, and 99 tons per square inch, sectional area of chip, for hard cast iron, when a fine feed is used.

In cutting the same piece of cast iron, the pressure of chip on the tool per square inch sectional area of chip grows considerably greater as the chip becomes thinner and slightly greater as the cut becomes more shallow in depth. The following are the high and low limits of pressure per square inch of sectional area of the chip when light and heavy cuts are taken on the same piece of cast iron:

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Depth of Cut $\frac{1}{8}''$ x Feed 0.0328″: Total Pressure per Sq. In. Sectional Area of Chip, 128,000 pounds;

Depth of Cut $\frac{3}{4}\frac{1}{4}''$ x Feed 0.1292″: Total Pressure per Sq. In. Sectional Area of Chip, 75,000 pounds.

The same fact mathematically expressed is that in cutting the same piece of cast iron the pressure of the chip on the tool per square inch sectional area of chip grows greater as the thickness of the chip grows less in proportion to (thickness of the feed) $^{\frac{1}{2}}$ or $F^{\frac{1}{2}}$.

The following formula expresses the general relation existing between the depth of cut and the feed, and the pressure on the tool for all the grades of cast iron experimented upon:

$$P = CD^{\frac{1}{16}}F^{\frac{1}{2}}$$

in which

P = The pressure on the tool;

D = Depth of Cut in Inches;

F = Feed in Inches.

C = A constant depending upon the softness or the hardness of the cast iron, and which varies between the limits of 45,000 for soft and 69,000 for hard cast iron.

The pressure of chip per square inch of section also grows greater as the depth of the cut grows less in proportion to (depth cut) $^{\frac{1}{16}}$ or $D^{\frac{1}{16}}$.

The effect upon the pressure of the chip on the tool of a change in the thickness of the feed and the depth of the cut is the same for hard and soft cast iron, and is represented by the same general formula with a change merely of the constant.

In taking cuts having the same depth and the same feed, the pressure of the chip on the tool becomes slightly greater the larger the cutting tool that is used. This increase in the pressure follows from the fact that the larger the curve of the cutting edge of the tool, the thinner the shaving becomes.

The most important conclusions arrived at regarding the pressure of the chip on the tool in cutting steel are:

The total pressure of the chip on the tool in cutting steel of the different qualities experimented upon by us varies between the low limit of 92 tons (2000 pounds) per square inch of sectional

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area of the chip, and the high limit of 168 tons (2000 pounds) per square inch sectional area of the chip.

In cutting the same piece of steel, the pressure of the chip on the tool per square inch of sectional area of the chip grows very slightly greater as the chip becomes thinner, and is practically the same whether the cut is deep or shallow. The following formula illustrates the relative pressure of a thin feed on the one hand and a coarse feed on the other.

Depth of Cut $\frac{3}{16}''$ x Feed 0.0156″: Total Pressure per Sq. In. Sectional Area of Chip, 295,000.

Depth of Cut $\frac{3}{16}''$ x Feed 0.125″: Total Pressure per Sq. In. Sectional Area of Chip, 257,000.

The same fact mathematically expressed is that in cutting the same piece of steel, the pressure of the chip on the tool per square inch of sectional area of the chip, grows greater as the thickness of the chip grows less in proportion to (thickness of the feed) $^{1}/_{8}$ or $F^{1}/_{8}$. The pressure of the chip is in direct proportion to the depth of the cut.

Within the limits of cutting speed in common use, the pressure of the chip upon the tool is the same whether fast- or slow-cutting speeds are used.

The pressure of the chip upon the tool depends but little upon the hardness or softness of the steel being cut, but increases as the quality of the steel grows finer. In other words, high grades of steel, whether soft or hard, give greater pressures on the tool than are given by inferior qualities of steel.

The pressure of the chip on the tool per square inch of sectional area of the chip depends upon both the tensile strength of the steel and its percentage of stretch, and increases both as the tensile strength and stretch increase; although a higher tensile strength has more effect than a large percentage of stretch in increasing the pressure.

Lastly, by far the most important conclusion arrived at by us in the field of "Pressure of the Chip on the Tool" is that the gearing designed in lathes, boring mills, etc., for feeding the tool should be sufficiently strong to deliver at the nose of the tool *a feeding pressure equal to the entire driving pressure of the chip upon the lip surface of the tool.* This fact was developed by us in an experiment made in the year 1883 in the works of the

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Midvale Steel Company, and had such an important bearing on the cost of turning out the product in the machine shop of those works that the results of this one simple investigation more than paid for all the experiments in the entire field of cutting metals undertaken in the Midvale Steel Works.

(7) *Cooling the Tool with a Heavy Stream of Water.* Chief among the conclusions derived along these lines are:

With high-speed tools a gain of 40% can be made in cutting steel or wrought iron by throwing, in the most advantageous manner, a heavy stream of water upon the tool.

In designing slide rules or tables, etc., for assigning daily tasks to machinists, a 33% increase in cutting steel or wrought iron should be allowed for instead of 40%, owing to the fact that workmen are more or less careless in directing the stream of water to the proper spot upon the tool.

A heavy stream of water (3 gallons per minute) for a 2″ x 2½″ tool, and a smaller quantity as the tool grows smaller, should be thrown directly upon the chip at the point where it is being removed from the forging by the tool. Water thrown upon any other part of the tool or the forging is much less efficient.

The gain in cutting speed through the use of water on the tool is practically the same for all qualities of steel from the softest to the hardest.

The percentage of gain in cutting speed through the use of water on the tool is practically the same whether thin or thick chips are being removed by the tool.

With modern high-speed tools a gain of 16% can be made by throwing a heavy stream of water on the chip in cutting cast iron.

To get the proper economy from the use of water in cooling the tool, the machine shop should be especially designed and the machine tools especially set with a view to the proper and convenient use of water.

In cutting steel, the better the quality of tool steel the greater the percentage of gain through the use of a heavy stream of water thrown directly upon the chip at the point where it is being removed from the forging by the tool. The gain for the different types of tools in cutting steel is:

(*a*) Modern high-speed tools 40%.

(*b*) Old-style self-hardening tools 33%.

(*c*) Carbon tempered tools 25%.

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This fact stated in different form is that: The hotter the nose of the tool becomes through the friction of the chip, the greater is the percentage of gain through the use of water on the tool.

(8) *Chatter of Tools.* The following are the general conclusions arrived at under this heading:

Chatter is the most obscure and delicate of all problems facing the machinist, and in the case of castings and forgings of miscellaneous shapes, probably no rules or formulæ can be devised which will accurately guide the machinist in taking the maximum cuts and speeds possible without producing chatter.

It is economical to use a steady rest in turning any piece of cylindrical work whose length is more than twelve times its diameter.

Too small lathe-dogs or clamps or an imperfect bearing at the points at which the clamps are driven by face plates produce vibration.

To avoid chatter, tools should have cutting edges with curved outlines and the radius of curvature of the cutting edge should be small in proportion as the work to be operated on is small. The reason for this is that the tendency of chatter is much greater when the chip is uniform in thickness throughout, and that tools with curved cutting edges produce chips which vary in thickness, while those with straight cutting edges produce chips uniform in thickness.

Chatter can be avoided, even in tools with straight cutting edges, by using two or more tools at the same time in the same machine.

The bottom of the tool should have a true, solid bearing on the tool support, which should extend forward almost directly beneath the cutting edge.

The body of the tool should be greater in depth than its width.

Chatter caused by modifications in the machine may be classified as follows:

(*a*) It is sometimes caused by badly made or fitted gears.

(*b*) Shafts may be too small in diameter or too great in length.

(*c*) Loose fits in the bearings and slides may occasion chatter.

(*d*) In order to absorb vibrations caused by high speeds, machine parts should be massive far beyond the metal required for strength.

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Chatter of the tool necessitates cutting speeds from 10% to 15% slower than those taken without chatter, whether tools are run with or without water.

Higher cutting speed can be used with an intermittent cut than with a steady cut.

Of all the difficulties met with by a machinist in cutting metals, the causes for the chatter of the tool are perhaps the most obscure and difficult to ascertain, and in many cases the remedy is only to be found after trying (almost at random) half a dozen expedients.

(9) *How Long Should a Tool Run Before Re-grinding?* The most important conclusions under this heading are:

It was only after fourteen years' work that we found that the best measure for the value of a tool lay in the exact cutting speed at which it was completely ruined at the end of 20 minutes.

If we note the proper cutting speed for a tool which is to last 20 minutes, and wish to find the cutting speed for a tool to last 40 minutes, multiply the 20-minute cut by 0.92.

If we have the proper cutting speed for a tool to last 20 minutes and wish to find the proper cutting speed for a tool to last 80 minutes, multiply the 20-minute cut by 0.84.

The curve approximating these values is represented by the following formula:

$$V = \frac{90}{T^{\frac{1}{4}}}$$

in which

V = speed of the tool in feet per minute;
T = length of time tool must last without grinding.

We have been unable to accurately determine the relation between the duration of the cut and the cutting speed for tools used in cutting cast iron. Such laws are badly needed.

Modern high-speed tools do a very much larger amount of work without re-grinding than carbon-tempered tools. The effect upon the cutting speed of the duration of the cut is shown by a comparison of modern high-speed tools with carbon tools where it was found that the high-speed tools fall off less in their cutting speed than the carbon tools, where they are run for a long time.

We call attention to the fact that as a measure of the value

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of a tool, the length of time which it can be run without being re-ground is a false and worthless standard. It is also well to note the radically different kind of wear which occurs with tools that last only a short while under cut and those which last for a longer time.

(10) *Effect of Feed and Depth of Cut on Cutting Speed.* The following principal conclusions were reached under this heading:

With any given depth of cut, metal can be removed faster, *i.e.* more work can be done, by using the combination of a coarse feed with its accompanying slower speed, than by using a fine feed with its accompanying higher speed.

The cutting speed is affected more by the thickness of the shaving than by the depth of the cut. A change in the thickness of the shaving has about three times as much effect on the cutting speed as a similar proportional change in the depth of the cut has upon the cutting speed. Dividing the thickness of the shaving by 3 increases the cutting speed 1.8 times; while dividing the length that the shaving bears on the cutting edge by 3 increases the cutting speed 1.27 times.

Expressed in mathematical terms, the cutting speed varies with our standard round-nosed tool approximately in inverse proportion to the square root of the thickness of the shaving or of the feed; *i.e.* S varies with $\sqrt{F}$ approximately.

With the best modern high-speed tools, varying the feed and the depth of the cut causes the cutting speed to vary in practically the same ratio, whether soft or hard metals are being cut.

(11) *Tool Steel and Its Treatment.* The improvements in the latest high-speed tools over the originals consist in:

(*a*) Far greater uniformity, owing to less danger in being injured in grinding and in daily use.

(*b*) 50% increase in cutting speed.

(*c*) The attainment of almost its maximum cutting speed without the necessity of the second or low-heat treatment.

(*d*) The combination in the same tool of the highest degree of red hardness with a high degree of hardness, thus requiring only one standard high-speed tool steel in the shop.

(*e*) The ability, owing to increased hardness, coupled with the necessary red hardness, to make the same proportionate gain when cutting with fine feeds upon hard metals as upon soft.

(*f*) Greater strength in the body.

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(*g*) The only point of inferiority is increased difficulty in forging at a cherry-red, and if blacksmiths are taught to forge their tools at a light yellow heat, these tools are easier to forge than the original high-speed tools.

(12) *Theory of Hardening Steel.*

(13) *Quality of Metal Being Cut.* Under this heading we have as a broad general guide to the cutting speeds to be used for cast iron with the scale on the castings just as they come from the foundry, that, as the average of several machine shops in this country, it is our observation that medium cast iron may be said to belong to Class 18 to 19 in our scale of hardness, and that when cutting with a standard $\frac{7}{8}$" tool of the quality of steel tool of No. 1, with a standard 20-minute cut, a $\frac{3}{16}$" depth of cut and $\frac{1}{16}$" feed, they have a cutting speed of 60 feet per minute. On the whole, what may be called the hardest castings frequently met with in machine shops are not harder than Class No. 24, giving a standard cutting speed of 35 feet per minute; while softer castings quite frequently met with are as soft as Class No. 11, and have a standard cutting speed of 120 feet per minute.

(14) *Line or Curve of Cutting Edge.*

(15) *Slide Rules.* It may seem strange to say that a slide rule enables a good mechanic to double the output of a machine which has been run, for example, for ten years by a first-class machinist, having exceptional knowledge of and experience with his machine, and who has been using his best judgment. Yet our observation shows that, on the average, this understates the fact.

427. Tests of High-speed Tool Steels on Cast Iron. Abstract from pamphlet issued by the Illinois Engineering Experiment Station at the University of Illinois.

The shape of the tool used in the tests is shown in Fig. 427*a*. The front clearance was 12½°, the top rake was 10° and the side rake was also 10°. Experiments relating to the proper shape of tools have been made by Prof. J. T. Nicholson, and the writers were guided in selecting proper tool angles by the recommendations of his paper.

Variation of Cutting Force with Area of Cut. The effort exerted by the tool in cutting was determined as explained before. The horse-power lost in driving the lathe and countershaft was deducted from the total horse-power used during the trial, the

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difference being the net horse-power used for cutting. This was reduced to foot pounds per minute and divided by the cutting speed, giving the force exerted. The figures so obtained were reduced to pounds per unit area of cut and plotted as ordinates upon a base of area of cut. See Fig. 427*b*. The curves show that the cutting force was not directly proportional to the area of cut but decreased as the area increased, and that the average cutting force varied from 50 tons per square inch for soft cast iron, to 85 tons per square inch for hard cast iron.

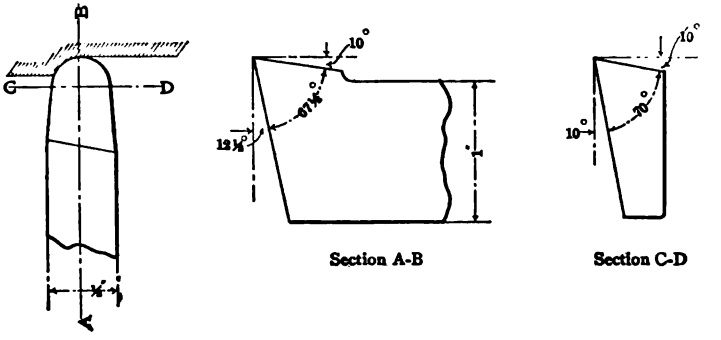

FIG. 427*a*.

Variation of Durability of Tool with Cutting Speed. An entirely arbitrary standard of durability was established as follows: A tool whose cutting edge was worn away .002″ after an hour's use was considered perfect, its durability being expressed as 100. The ratios of the durability of any other tools to the standard will then be the inverse of the ratios of their rates of wear to the rate of wear of the standard.

In Fig. 427*c* are shown the curves which represent the relation between the durability of the tool and the cutting speed. These are important curves. Each curve represents a different hardness of cast iron. Referring to the middle curve, which is for cast iron of medium hardness, it will be seen that a cutting speed of 50 feet per minute is satisfactory, the durability being 100. If the speed is increased very materially, the durability decreases quite rapidly. It is evident that for each hardness of cast iron the cutting speed allowable for a maximum durability exists where the vertical line indicating cutting speed is tangent to curves similar to those drawn.

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Variation of Cutting Speed with the Hardness of Cast Iron. The curve shown in Fig. 427*d* represents the advisable cutting speed on cast iron of varying hardness. This curve represents the result of all the tests of the different steels tested. This curve

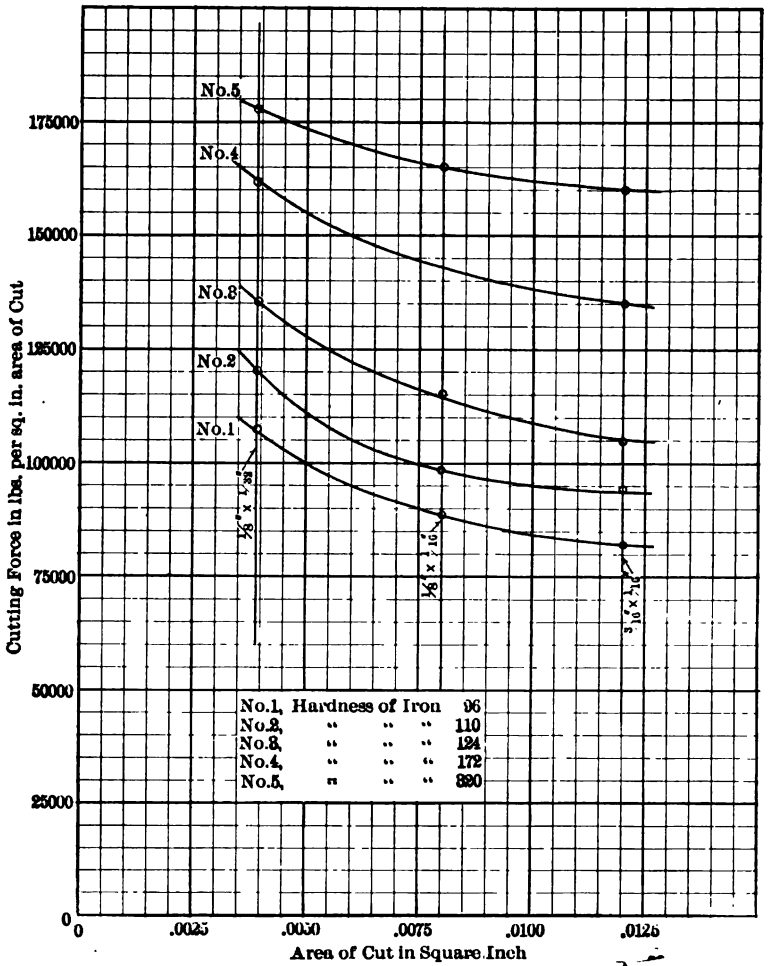

FIG. 427*b*. — Curves Showing Relation between Cutting Force on Point of Tool and Area of Cut for Cast Iron of Varying Hardness.

shows: (*a*) that any of the steels tested can remove very hard cast iron at a rate of 25 feet per minute; (*b*) that all of the steels tested begin to wear rapidly at speeds a little above 125 feet per

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minute. Between these two points the relation between a safe cutting speed and the hardness of the cast iron seems to be definitely expressed by the curve. It would seem that cast iron

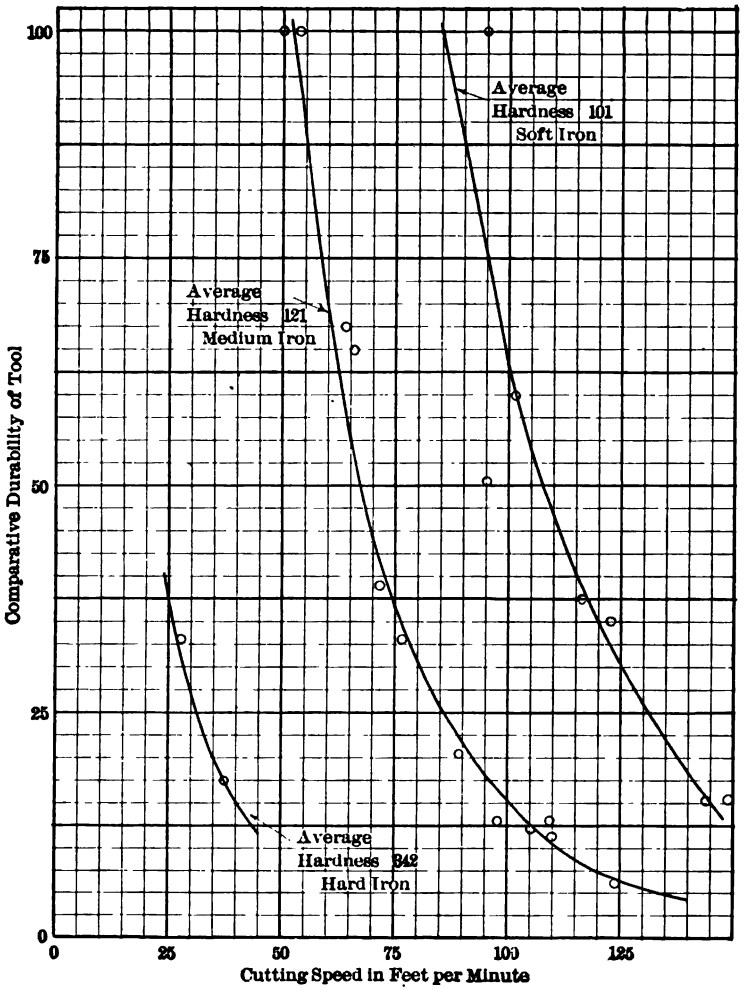

FIG. 427*c*. — Curves Showing Variation of Durability of Tool with Cutting Speed for Cast Iron of Varying Hardness.

of medium hardness, 100 to 120, could be cut at 125 feet per minute just as readily as at 70 feet per minute, so far as any injury to the tool is concerned. It must be remembered that

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this curve does not take into account the effect, on the cutting speed, of the variation in the area of cut; the experiments from which the curve was plotted were in all cases those in which the

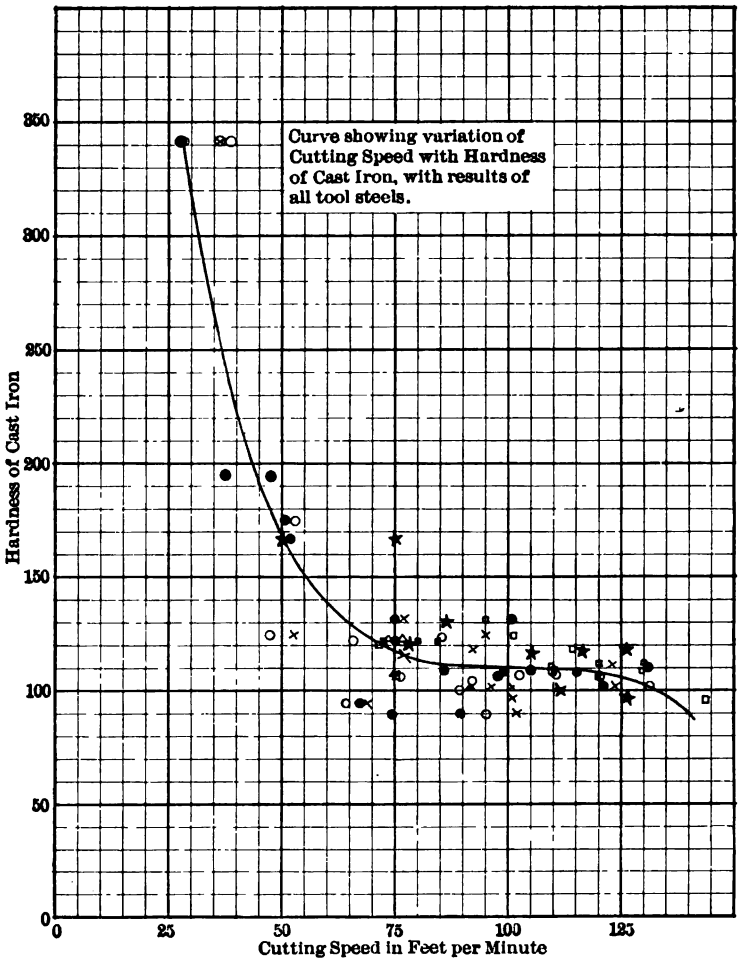

FIG. 427*d*. — Curves Showing Cutting Speeds Best Adapted to Use with a Variation in the Hardness of Cast Iron.

cut was very nearly $\frac{1}{8}''$ depth of cut by $\frac{1}{16}''$ feed, so that there is but a slight variation in the area of cut in all of the experiments. From the curve of Fig. 427*d* we find the cutting speed given in the table below to be applicable to the grades of iron manufac-

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tured by the different companies sending test pieces. In order that any company may make use of the curve shown in this figure, it will be necessary simply to determine the average hardness of its cast iron, as explained elsewhere, and where the horizontal line representing this hardness cuts the curve, the possible safe cutting speed may be read on the scale below.

ALLOWABLE CUTTING SPEED FOR GRADES OF CAST IRON USED IN THE TESTS

Average Hardness Test Pieces	Allowable Cutting Speed	Average Hardness of Test Pieces	Allowable Cutting Speed
101.8	132.0	103.1	132.0
110.7	118.0	132.0	63.0
109.3	120.0	343.0[1]	28.0
112.7	90.0	175.2	48.0
148.1	60.0	136.3	60.0

[1] Ferro-steel.

Generally speaking, all the steels tested proved equally effective. It is very evident that there are great possibilities ahead for the high-speed steels. Before realizing their full benefit, however, certain advances must be made. Heavier machine tools must be built. The capacity of the motors and power plant must be increased. Special hardening furnaces with temperature measuring devices must be available. More must be known concerning the chemical and physical properties of the various steels.

The following sentences are abstracted from a paper on the "New Tool Steel and its Effect on Machine Shop Methods," by Prof. C. I. King: "Forgings of 36″ in diameter have been reduced to 28″ at one cut. As a result of this recently acquired knowledge, line shaft speeds have been increased from 90 to 250 revolutions per minute; cutting speeds are increased 180%, depth of cut 30%, the rate of feed by 24%, and the end is not yet in sight." Professor King predicts planer and shaper speeds of 100 feet per minute.

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428. Revolutions for Given Diameter and Cutting Speeds.

Diameter of Piece	Cutting Speeds in Feet Per Minute													
	10	15	20	25	30	35	40	45	50	55	60	70	80	90
	Revolutions Per Minute of Piece													
1/4	153	229	306	382	458	535	611	688	764	840	916	1070	1222	1376
3/8	102	153	204	255	306	356	407	458	509	560	612	712	814	916
1/2	77	115	153	191	229	267	306	344	382	420	458	534	612	688
5/8	61	92	122	153	183	214	244	275	306	336	366	428	488	550
3/4	51	76	102	127	153	178	204	229	255	280	306	356	408	458
7/8	37	65	87	109	131	153	175	196	218	240	262	306	350	392
1	38	57	76	95	115	134	153	172	191	210	230	268	306	344
1 1/4	31	46	61	76	92	107	122	137	153	168	184	214	244	274
1 1/2	25	38	51	64	76	89	102	114	127	140	152	178	204	228
1 3/4	22	33	44	55	65	76	87	98	109	120	130	152	174	196
2	19	29	38	48	57	67	76	86	95	105	114	134	152	172
2 1/2	15	23	31	38	46	53	61	67	76	84	92	106	122	134
3	13	19	25	32	38	45	51	57	64	70	76	90	102	114
3 1/2	11	16	22	27	33	38	44	49	55	60	66	76	88	98
4	9	14	19	24	29	33	38	43	48	53	58	66	76	86
5	8	11	15	19	23	27	31	34	38	42	46	54	62	68
6	6	9	13	16	19	22	25	27	32	35	38	44	50	54
8	5	7	10	12	14	17	19	21	24	26	28	34	38	42
10	4	6	8	10	11	13	15	17	19	21	22	26	30	34
12	3	5	6	8	9	11	13	14	16	18	18	22	26	28
14	3	4	5	7	8	9	11	12	14	15	16	18	22	24
16	2	4	5	6	7	8	9	11	12	13	14	16	18	22
18	2	3	4	5	6	7	8	9	11	12	12	14	16	18
24	1	2	3	4	5	6	6	7	8	9	10	12	12	14

For greater cutting speeds multiply by 2.

FIG. 428.

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429. Examples of Recent Practice with High-speed Tool Steels. Turning, Milling, Drilling and Planing.

TURNING

Material	Speed in Ft. per Min.	Feed in Inches	Depth Cut in Inches	Weight of Metal Removed. Lbs. per Minute	Actual H. P.	Size of Lathe	Brand of Steel Used	Date	Authority
Cast Iron.	47	1/16	1/4	2.3	2	30″		1906	G. M. Campbell at Penn. & L. E. Shops.
	58	1/16	3/16	2.12	2.2	42″		1906	
	108	1/16	1/8	2.63	5 8	42″		1906	
Soft C. Ir. Av. Hardn. 102.8 ...	132	1/16	1/8	—	—			1906	
Av. Hardn. 110.7 ...	118	1/16	1/8	—	—	16″ High Speed, Pratt & Whitney.	See Note	1906	Illinois.
Do. 132.0.	63	1/16	1/8	—	—			1906	
Do. 138.1.	60	1/16	1/8	—	—			1906	Eng.
Do. 175.2.	48	1/16	1/8	—	—			190	Exp.
Ferro-Steel 343.0 ...	28	1/16	1/8	—	—			1906	Station
Wrot. Iron	54	1/8	3/16	4.2	6.6	30″		1906	Campbell at P. & L. E.
Forged Steel ...	32	1/4	1 1/4	33.9	60 H.P Motor	Armstrong & Whitworth Co. Special 36″.	Armstrong &Whitworth.	1906	Armstrong & Whitworth by J. M. Gledhill.
	38	1/2	1/2	32.2				1906	
	42	1/4	1″	35.6				1906	
	100	1/8	1″	42.4				1906	
	160	1/16	3/16	10.2				1906	
Soft Steel.	12.5	5/16	1/2	6.9	12.7	Car Wheel Lathe, Axle Lathe, 32″ Gisholt.	Armstrong &Whitworth.	1906	G. M. Campbell at P. & L. Erie Shops.
	43	1/16	5/16	3.4	4.9			1906	
	94	1/32	3/16	1.9	3.6			1906	
Machinery Steel ...	48	1/8	5/16	6.4			Mushet.	1904	A. Waterman, Worcester.
Hard Steel	13.2	3/8	3/8	6.3	12	72″ Wheel.	—	1906	G. M. Campbell at P. & L. Erie.

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TURNING (*continued*).

Material	Speed in Ft. per Min.	Feed in Inches	Depth Cut in Inches	Weight of Metal Removed. Lbs. per Minute	Actual H. P.	Size of Lathe	Brand of Steel Used	Date	Authority
20 Pt. Carbon Steel	80	$\frac{1}{8}$	$\frac{3}{8}$	21.4	—	D. S. & Grace, 24″	Taylor-White.	1904	Dean, Smith & Grace.
	205	$\frac{1}{8}$	$\frac{1}{16}$	6.1	—				
Siemens-Martin Steel....	65	$\frac{1}{4}$	$\frac{3}{8}$	34.5		32″ Special	Mushet.	1906	Sam Osborn Co. England.

FIG. 429*a*.

NOTE. — Generally speaking, all steels tested proved equally effective. "Bohler Rapid," Jessup's "Ark," McInnesses' "Extra," "Air Novo," "Rex," "Poldi" and Armstrong and Whitworth were used.

MILLING

Material	Speed in Feet Per Minute	Table Travel. Inches Per Minute	Cut. Depth in Inches by Width in Inches	Weight of Metal Removed. Lbs. Per Minute	Actual H. P.	Cutter		Size of Milling Machine	Brand of Tool Steel in Cutter	Date	Authority
						Dia.	Face				
Cast Iron.	59	15	$\frac{3}{32}$ x $8\frac{1}{2}$			$3\frac{3}{4}$	9	Cin. No. 4 Plain	Usona	1906	Colcord Mach. Co.
"	80 & 30	3.8	$\frac{3}{16}$ x $11\frac{1}{2}$			3 to $8\frac{1}{4}$	Gang	"	"	"	"
"	83	27	$\frac{1}{8}$ x $1\frac{1}{4}$			4	$1\frac{1}{2}$	Cin. No. 3 Plain	"	"	"
"	83	3.7	$\frac{3}{4}$ x 1			$\frac{3}{4}$	$1\frac{1}{2}$	Plain Cin. No. 2	Novo	1905	Cin. Mill. Mach. Co.
"	90	27	$\frac{3}{32}$ x 3			4	$3\frac{1}{2}$	Plain Cin. No. 3	"	"	"

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MILLING (*continued*).

Material	Speed in Feet Per Minute	Table Travel. Inches by Minute	Cut. Depth in Inches by Width in Inches	Weight of Metal Removed. Lbs. Per Minute	Actual H. P.	Cutter		Size of Milling Machine	Brand of Tool Steel in Cutter	Date	Authority
						Dia.	Face				
Cast Iron.	130	36	$\frac{1}{8}$ x 1			2	Vert	Plain Cin. No. 2	Novo "	1905 "	Cin. Mill. Mach. Co.
Gray Iron.	80	8	$\frac{3}{16}$ x 6$\frac{1}{2}$			8	Vert	Plain Cin. No. 4	"	1906	"
"	107	4	$\frac{3}{4}$ x 6	305	40 H.P. Motor	5		Spec. A. & Whitw.	Arm. & Whitw.	1906	Armstrong & Whitworth
Forged Steel.	75	1.2	1$\frac{1}{2}$ x 7$\frac{1}{2}$	191	"	6	12	"	"	"	By J.M. Gledhill
"	180	6	$\frac{1}{2}$ x 7$\frac{1}{2}$	382	"	6	12	"	"	"	"
"	192	8	$\frac{1}{8}$ x 7$\frac{1}{2}$	157	"	6	13	"	"	"	"

CUTTING SPEED IN FEET PER MINUTE FOR SURFACING AND SLABBING WITH USONA CUTTERS

Average Depth of Cut $\frac{1}{8}$"

Material Cut	Feet per Minute
Annealed Carbon Steel	20
Well Annealed Tool Steel	40
Soft Machine Steel, Wrought Iron, Hard White Iron Castings, Open Hearth Steel Castings Cast in Dry Sand Molds	60
Medium Hard Iron Castings, Phosphor Bronze, Tobin and Aluminum Bronzes	60 to 80
Soft Gray Iron Casting, Malleable Iron Castings, Soft Semi-Steel Cast	70 to 90
Red Brass	120
Yellow Brass	140

FIG. 429*b*.

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DRILLING

Material	Size of Drill	Speed, Ft. per Min.	Rev. Drill per Min.	Feed In. per Min.	Cuts per In. of Tra.	Actual H. P.	No. of Holes Drilled	Condition of Drill	Brand of Tool Steel	Date	Authority
2″ Gray Cast Iron	$\frac{15}{32}$	129	630	18	35		400	Good	A. & W.	1906	Arm. & Whit. by J. M. Gledhill
3″ Gray Cast Iron	$\frac{3}{4}$	140	725	17	42			"	Mushet	1906	Sam. Osborn Sheffield
Wrought Iron	2	20.9	37	$\frac{1}{64}$		1.7	Wgt. Metal Removed .54 lbs. per min.	"		1906	G. M. Campbell, P. & L. E. Shops
"	$1\frac{1}{4}$	74.5	228	$\frac{1}{64}$		$3\frac{1}{2}$	.52 lbs.	"		1906	"
Two $\frac{1}{8}$″ Steel Plates Together	$\frac{1}{4}$	32.5	Max. of Drill 497	10.8	46		28 holes	End Broke	A. & W. High Speed	1906	"
"	$\frac{3}{8}$	48.8	497	10.8	46		50 "	Good	"	1906	"
"	$\frac{1}{2}$	65	497	10.8	46		50 "	"	"	1906	"
"	$\frac{5}{8}$	81.3	497	10.8	46		50 "	"	"	1906	"
"	$\frac{3}{4}$	97.6	497	10.8	46		50 "	"	"	1906	"
"	1	130.1	497	10.8	46		50 "	"	"	1906	"
Siemens Steel .30C, 3″ Thick...	$2\frac{5}{16}$	66	111	$3\frac{1}{2}$	32			"	Mushet	1906	Sam. Osborn Sheffield

FIG. 429c.

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PLANING

Material	Speed in Ft. per Min.	Feed in Inches	Depth of Cut Inches	Wgt. Met. Removed Lbs. per Min.	Actual H.P.	Size of Planer	Brand of Steel	Date	Authority
Cast Iron...	28.9	$\frac{1}{4}$	$\frac{5}{16}$	18.3	23.2	60"		1906	G. M. Campbell at P. & Lake Erie Shops
"	37	$\frac{3}{16}$	$\frac{1}{16}$	4.6	4.7	42"		1906	"
"	40	$\frac{3}{16}$	$\frac{1}{16}$	1.46	2.6	42"		1906	"
Wrot. Iron..	23	$\frac{8}{16}$	$\frac{5}{16}$	8.95	21	60"		1906	"
"	25	$\frac{5}{32}$	$\frac{3}{8}$	4.87	12.3	42"		1906	"
"	36	$\frac{1}{8}$	$\frac{3}{8}$	5.7	7.8	42"		1906	"
Mach. Steel.	90	$\frac{3}{8}$	$\frac{1}{4}$	47	100 H. P. Motor	42"	Novo	1904	L. P. Exposition, St. Louis, Mo.

FIG 429*d*.

HAND TOOLS, GRINDING AND USE

431. Chisels.

The Flat or Cold Chisel. This is the most common of all machinist's chisels and is often referred to as simply a cold chisel. It is generally used whenever any hand chipping or cutting is to be done. The cutting edge should be slightly convex with its faces ground and whetted at an angle of 60° with each other.

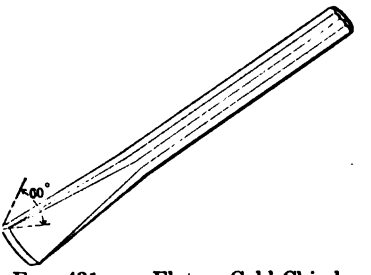

FIG. 431*a*. — Flat or Cold Chisel.

The Cape Chisel. This chisel is similar in its use and action to the flat chisel and is most frequently employed in chipping keyways, square grooves and where large, flat surfaces are to be

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chipped, for driving a number of grooves across it before using the flat chisel.

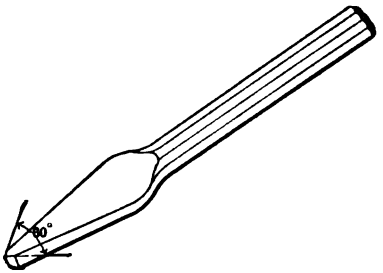

FIG. 431*b*. — Cape Chisel.

The Round-nose Chisel. This chisel is used principally for grooving oilways, similar work, and in drilling, to cut out a new path for the drill when the hole is improperly centered.

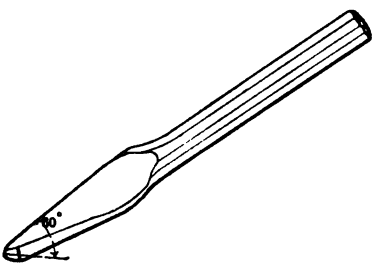

FIG. 431*c*. — Round-nose Chisel.

432. Gravers. Metal turning in the speed lathe is accomplished by means of gravers. Although a speed lathe is used to obtain a higher speed for the work, the cutting action of gravers depends upon the laws of rake and clearance. They are used chiefly for finishing pieces of irregular outline, curves and for turning very small pins. As compared with other tools, their cutting power is small. Gravers are commonly made from worn-out files, preferably those of square section, and their cutting edges ground to that particular shape best adapted to the work.

The Diamond-point Graver. This tool is principally used on convex surfaces and for rounding corners on such work as the end of a bolt or screw. The proper angles of rake and clearance

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are easily determined by noting the chips; to obtain the best results the cutting edge should be whetted keen and straight.

The Round-nose Graver. The principal use of this tool is for roughing and for finishing concave surfaces.

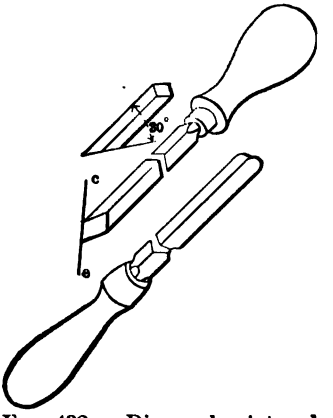

FIG. 432. — Diamond-point and Round-nose Gravers.

433. Scrapers. Where great accuracy is desired, as it is quite impossible to produce a true, plane surface with a planer or file, scrapers are resorted to. A scraper is usually a blunt chisel-shaped tool with two or more exceedingly hard cutting edges, ground with a large (obtuse) angle of keenness. Different forms of scrapers are used for different kinds of work; the flat and three-cornered scrapers being the common forms. Scrapers are used for truing surfaces and for fitting flat bearing surfaces to each other. Errors to be removed by scraping should not exceed two or three thousandths of an inch. Scrapers, though often made of old files, should be made of the best grades of tool steel, as "file steel," when once annealed, can only be properly hardened by a special process. Good scrapers may, however, be made of old files when no forging is necessary and when great care is exercised not to overheat the steel while grinding.

The Flat Scraper. This scraper is the easiest to make, sharpen and use, and in expert hands it will remove an astonishing amount of surface in a short time. The cutting edge should be drawn out to about $\frac{1}{16}$″ thick by $1\frac{1}{4}$″ wide and hardened to the greatest

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degree. The end is ground slightly convex, like the end of the flat chisel, while the sides are ground flat. The end of a scraper

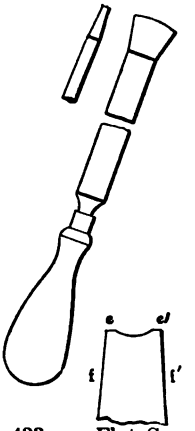

FIG. 433*a*. — Flat Scraper.

should be ground on a wheel of a small diameter in such a manner as to produce two cutting edges, *e* and *e'* (Fig. 433*a*). In whetting the faces, *f* and *f'*, the stone should bear on them; in whetting the cutting edges, the tool is held in a vertical position so

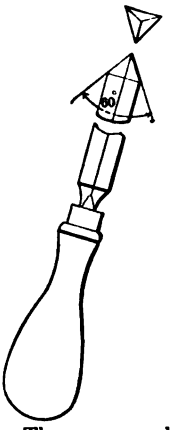

FIG. 433*b*.—Three-cornered Scraper.

that the edges *e* and *e'* rest upon the stone; in this position the tool is moved back and forth until sharp.

The Three-cornered Scraper. See Fig. 433*b*.

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Lathe Tools

441. The Diamond-point Tool. This is the most common of all lathe tools. On account of its shape and owing to its being ground with both top and side rake, it easily removes the chip and may be used on either roughing or finishing cuts. In adjust-

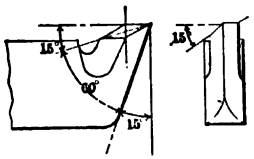

Fig. 441. — Diamond-point Tool.

ing the tool, it should be set with just enough clearance to avoid friction and as much top rake as the condition will allow.

442. The Round-nose Roughing Tool. This tool is generally used for roughing cuts on cast iron, and sometimes, on account of its small amount of top rake, on the softer metals. It is also used for turning grooves, rounding out corners, and in many places that are inaccessible with the diamond-point tool.

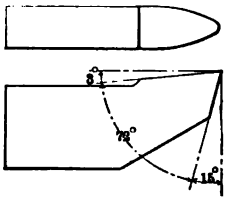

Fig. 442. — Round-nose Roughing Tool.

443. The Side Tool. This tool is used for producing the flat surfaces in lathe work, such as facing and end turning. To obtain the best results, the cutting edge should be slightly convex toward the work and whetted keen and smooth. See Fig. 443.

Note. A right-hand tool is designed to cut from right to left and a left-hand tool, *vice versa*. Water should be used for grinding all carbon steel tools. Cutters of self-hardening or tungsten steel may be ground dry.

444. The Parting or Cutting-off Tool. As its name implies,

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this tool is used for partings, for cutting off small pieces of round stock, for square grooving and where square corners are desired. To work well this tool should be thickest on the cutting edge

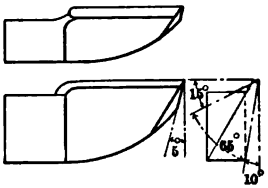

FIG. 443. — Side Tool.

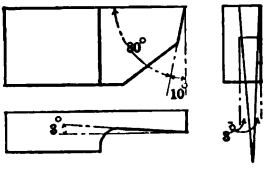

FIG. 444. — Parting or Cutting-off Tool.

and have ample clearance on all sides. It is generally set on a line with the centers.

445. The Boring Tool. This tool is used for turning the inside of cylinders — boring. Its shape and grinding depend largely upon the metal to be cut; however, what has been said in general about tools will apply. The theoretical height of this tool is below the center for the same reason that for outside tools it is above the center; for other reasons it is generally placed on the center line and ground for scant clearance in this position.

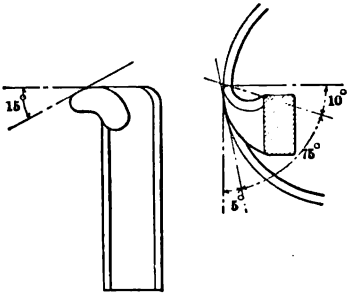

FIG. 445. — Boring Tool.

446. The Bull-nose Tool. This tool is similar in use and action to the diamond point; on account of its shape and rounded cutting edge it partakes in a way of the properties of both the diamond point and the round nose. It is also used for roughing a facing cut. See Fig. 446.

447. The Threading Tool. U. S. Standard. This tool is used for ordinary screw cutting. The 60° angle of the cutting edges

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should be tested with the center gage for truth, and the point ground flat with a width equal to $\frac{1}{8}$ the pitch of the thread. In

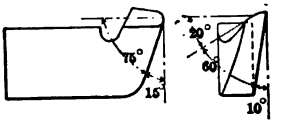

FIG. 446. — Bull-nose Tool.

adjusting the tool, the cutting edges should always be placed in a line with the centers, and so that a center line between them is perpendicular to the surface on which the thread is to be cut.

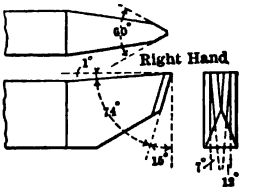

FIG. 447. — Threading Tool, U. S. Standard.

The angularity of the particular thread to be cut must be taken into consideration when grinding for clearance.

448. The Finishing Tool. As the name implies, this tool is

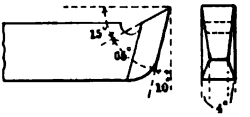

FIG. 448. — Finishing Tool.

used for taking a finishing cut. It is generally employed on large work and where a coarse feed is permissible.

449. The Brass-working Tool. This tool, somewhat similar

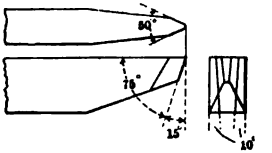

FIG. 449. — Brass-working Tool.

in shape to the threading tool, is flat on top, has no top rake, and is generally ground with more side clearance than the iron and steel-working tools.

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Planer Tools

451. Discussion and Theory. In general, the theory underlying all metal cutting tools is the same; and the planer tool forms no exception to the rule. The student is advised to review what has been said in the discussion of the governing conditions of cutting tools in the earlier part of this chapter.

The most noticeable difference between the grinding of planer and lathe tools arises from the fact that the tool-box on planing machines is rigid and provides no adjustment for altering the angles of top rake and clearance, as does the "rest" of a lathe. With planer tools, the shank of the tool is always perpendicular to the platen and whatever angles are determined upon must be obtained by grinding; the keenness depending upon the angles of top rake, side rake and clearance, while the strength depends upon the angles of top rake and clearance. The angle of clearance for planer tools is small, varying from about 3° to 7°. Tools for steel and wrought iron have usually a more acute angle of keenness than those for cast iron. In some instances roughing tools for cast iron have no top rake whatever, keenness being obtained by side rake. As was the case in turning, the work is finished by the roughing cuts and a finishing cut; the roughing cuts being as heavy as the tool and the work will permit; usually deep with fine feed. For finishing cast iron, the finishing cut is generally very light and made with a broad, square-nosed tool, the feed being almost equal to the width of the tool; however, for planing surfaces that are subsequently to be scraped, the average feed is about $\frac{1}{10}''$.

For finishing steel or wrought iron, the point of the tool is flat, but much narrower than for cast iron.

452. The Roughing Planer Tool. This tool is similar in shape to the round-nose roughing lathe tool and is used for the same class of cuts; its general use being for roughing cuts on cast iron and sometimes, on account of its small amount of top rake, it is also used on the softer metals. Though the general shape of this tool remains the same, the contour of the cutting edge and the angles of rake and clearance are varied slightly in conformity with the nature and depth of the cut and the texture of the material. By bending the shank of this tool either to the right or to the left, and grinding a straight portion on the cutting

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edge, we have a tool that is often used instead of side tools.

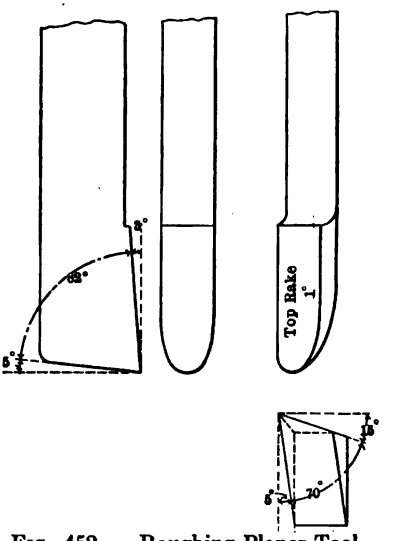

FIG. 452. — Roughing Planer Tool.

453. The Diamond-point Planer Tool. This tool is being rapidly superseded by the various roughing tools, because of the ease with which they are forged; however, the diamond point, on account of its shape and owing to its being ground with both top and side rake, easily removes the chip and is used either for roughing or finishing cuts.

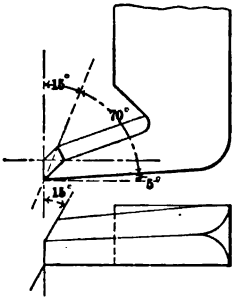

FIG. 453. — Diamond-point Planer Tool.

454. The Straight-edge Side Tool (Planer). This tool is used for facing and is similar in shape to the side tool used in lathe

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work, with the exception that the cutting edge, instead of being parallel with the shank of the tool, is forged so that it inclines toward the back. This lessens the shock when starting the cut,

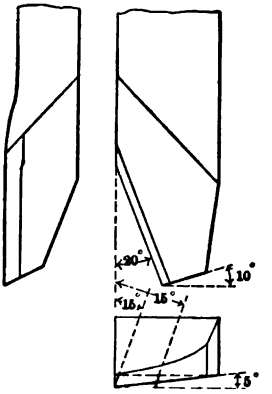


FIG. 454. — Straight-edge Side Tool, Planer.

which increases gradually as the tool advances, producing somewhat of a shearing action and downward pressure, which tends to hold the work to the platen.

455. Slotter Tools.

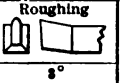
		Corner	Square	Splining	Hex. for Wrench	Roughing
						
Faces	Top	—	d 4°	4°	0°	8°
	End	a 7°	a 0°	0°	a & b 4°	4°
	L Side	b 4°	b 4°	0.3°	4°	4°
	R Side	c 4°	c 4°	0.3°	4°	4°

FIG. 455. — Slotter Tools.

456. Shapes and Grinding of 25 Straight-faced Planer Tools.

The tables show the various shapes of the common planer (Fig. 456) and slotter tools (Fig. 455), and their angles of rake, keenness and clearance; the angles herein are taken, in the main, from the grinding charts furnished by Wm. Sellers & Co., and the Gisholt Machine Co., with their universal tool grinders, and are fairly indicative of modern practice in this direction.

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PLANER TOOLS						
		Chamfering	R Bent Finish	L 30° Angle	Side Finish	Finishing
Faces	Top	0°	6°	0°	18° & 5°	7°
	End	—	4°	a 4°	b 6°	4°
	L Side	a 5°	2°	6°	7°	—
	R Side	b 5°	2°	b 4°	a 7°	—
		45° Ang. Slot	L Bent Fin.	30° Angle R.	R. Side Fin.	Splining
Faces	Top	0°	0°	0°	18° & 5°	0°
	End	4°	4°	a 4°	b 6°	4°
	L Side	4° a 4°	2°	b 4°	7°	2°
	R Side	4° b 4°	2°	6°	a 7°	2°
		L 30° A Slot	L 45° Angle	L 40 Angle	L Bent Side Fin	L Cutting Down
Faces	Top	0°	0°	0°	18° & 5°	0°
	End	4°	4°	4°	b 6°	4°
	L Side	4°	6°	6°	7°	0°
	R Side	a 4°	b 4°	b 4°	a 7°	—
		R 30° A Slot	R 45 Angle	R 40° Angle	R Bent Side Fin	R Cutting Down
Faces	Top	0°	0°	0°	18° & 5°	0°
	End	4°	4°	4°	b 6°	4°
	L Side	a 4°	b 4°	b 4°	a 7°	—
	R Side	4°	6°	6°	7°	0°
		Rough Side	L Side	Roughing	Cutting Down	Grooving
Faces	Top	15° & 8°	15° & 5°	18° & 8°	2°	0°
	End	5°	5°	6°	4°	5°
	L Side	5°	5°	7°	6°	5°
	R Side	—	—	—	6°	5°

FIG. 456. — Planer Tools.

TOOL HOLDERS WITH SELF-HARDENING STEEL CUTTERS

461. Lathe Tools. This style of tool is superseding the hand-forged tool for ordinary work for the following reasons: One tool and cutter take the place of the diamond-point, round-nose, bull-nose and finishing tool. The cutters are made of the finest quality of tungsten steel, and being small, and of easily rolled sections, cost far less in comparison than a forged tool. Forging and tempering are entirely dispensed with, while grinding is reduced to a minimum. The cutters may be ground to any desired shape or clearance and the cutting edge always keeps at the same height. They will work either right or left hand and close into a corner.

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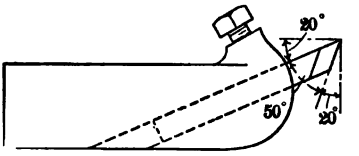

FIG. 461. — Lathe Tool-holder.

462. Planer Tools. Like similar tools for the lathe, this style of tool is superseding the hand-forged tools for ordinary work for the same reasons. See Section 461. It is essential that the cutter be held rigid, and with the Armstrong holders the cutter may be placed at various angles, adapting itself easily to a

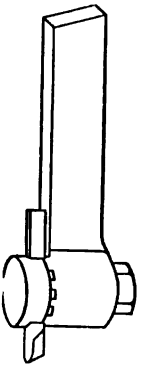

FIG. 462. — Planer Tool-holder.

variety of work. With this class of holder, reversing it, — *i.e.*, placing the cutter in the rear instead of in advance of the shank — often prevents gouging and chattering. Later varieties of holders provide several cutters, each of which takes its own chip, thus multiplying the output by the number of cutters used.

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CHAPTER V.

MEASURING AND SMALL TOOLS

Standards of Measurement

511. Historical Statement. A measuring tool is an instrument or device that is used to compare or measure linear or other dimensions with some standard unit.

The following bit of historical information is taken from the Brown & Sharpe catalog: "The Standard Yard was first legalized in England in 1824. This standard, however, was destroyed in 1834. The Standard Imperial Yard, 'Bronze No. 1,' was then prepared and legalized in 1855. Forty copies were made; and one of these, 'Bronze No. 11,' was presented to the United States by the British Government in 1856. At the same time another copy, known as 'Low Moor Iron No. 57,' was sent. These were accurately compared, before being sent, with the Standard Imperial Yard, and the record of the variations sent with them.

"Although the Constitution of the United States empowered Congress to fix the standards of weights and measures, no legal standard of length was adopted until 1866, when a law was passed making the meter legal, the first and only measure of length legalized by the United States Government.

"We prepared standards for use in our own shops, and, after their completion, they were compared by the Government officials with the standards in Washington. The mean errors were found to be: for the yard, .00002″, and for the meter .000006M, both being too long."

Direct Measuring Tools

521. Rules. The commoner machinist's measuring tools are the following: the steel rule, the try square, the micrometer caliper, the micrometer caliper square, the bevel protractor, the center square and various minor standards called gages.

The Standard Steel Rule. The most common of all machinist's

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measuring tools is the standard steel rule. These rules can be conveniently introduced into grooves and countersinks of various kinds, and are adapted for this class of measurement as well as for ordinary use. Owing to the simplicity of the steel rule a description is hardly necessary. It may be purchased with a

FIG. 521. — Steel Rule.

variety of graduations; however, that graduation seemingly best adapted for ordinary work is the one having the inches on each of the four edges divided respectively into 16ths, 32ds, 64ths and 100ths. In direct measurement the lines on the rule are made to coincide with the distances measured, while for indirect measurement, calipers or dividers — whose points are made to coincide with the graduation lines — are used. Great care should be exercised in the taking of the finer measurements, as carelessness may lead to the mistaking of one division for another and thus ruining the work.

522. The Try Square. Try squares are used by machinists to test the truth and accuracy of surfaces at right angles to each

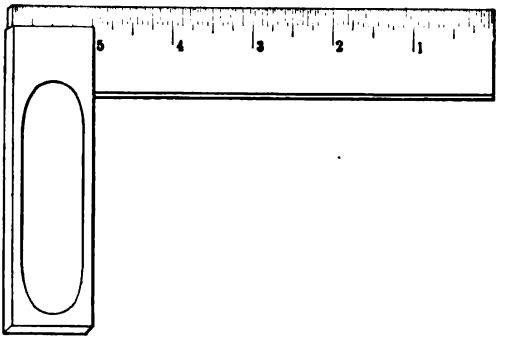

FIG. 522. — Graduated Hardened Steel Square.

other. No machinist's small shop tool requires more accuracy in its construction than does the try square. The stocks and edges of the blades are sometimes hardened and in most cases are accurately ground for parallelism and for straightness.

523. The Micrometer Caliper. The micrometer caliper forms

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a convenient and accurate tool for external measurements and is used by the machinist for taking accurate measurements on fine work. The readings of this tool generally give the dimensions in

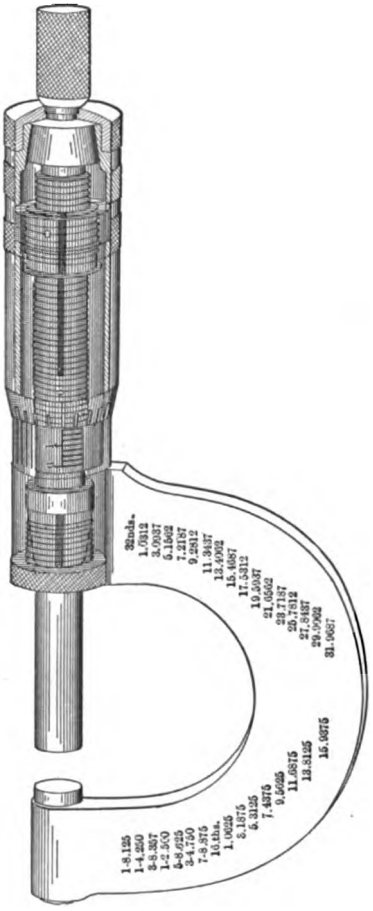

FIG. 523*a*. — Micrometers with Ratchet Stop.

thousandths of an inch; however, micrometer calipers may be purchased whose readings give the dimensions in ten thousandths of an inch. Like most shop tools micrometer calipers are made in a variety of sizes and styles, the essential parts being (Fig. 523*b*) the *micrometer screw or spindle C* to which is attached a *thimble E*, the front end of which is beveled and graduated; a

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graduated barrel or sleeve D ; an *anvil B* on which the work is placed for measurement; and a *frame A* carrying these parts.

The following principle is the one on which the micrometer caliper is based: If a screw of known pitch be turned one revolution through its nut, it will have moved a distance equal to the pitch of the thread; if the screw be rotated through a fraction of a revolution, its linear motion will be a similar fraction of its pitch. Micrometer screws are generally made with forty (40) threads to the inch, and have the circumference of the beveled edge of the thimble divided into twenty-five (25) equal parts; if now the thimble be turned a distance equal to one of these graduations, the linear motion of the screw will be $\frac{1}{25}$ of $\frac{1}{40}$ or $\frac{1}{1000}$ inch. The barrel, in which the screw operates and over

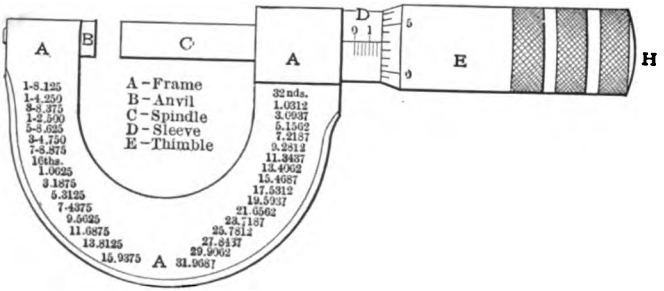

FIG. 523*b*. — Micrometer Nomenclature.

which the thimble fits, is graduated, perpendicularly to the axis of the screw, into 40ths of an inch, these divisions being marked 0, 1, 2, etc., every fourth division. As these graduations conform to the pitch of the screw, each division equals the linear distance traversed by the screw in one complete revolution, indicating a movement of $\frac{1}{40}$ inch. The reading is made by multiplying the number of divisions visible on the scale on the barrel by 25, adding to this product the number of divisions on the scale on the thimble, from the zero graduation to the line coincident with the line of graduations on the barrel. These calculations may be made mentally: for example, suppose that the number of visible graduations of the barrel is 5, and the number of divisions registering on the thimble scale is 7. Then $5 \times 25 = 125$; $125 + 7 = 132$, which is the number of thousandths between the anvil and the end of the screw.

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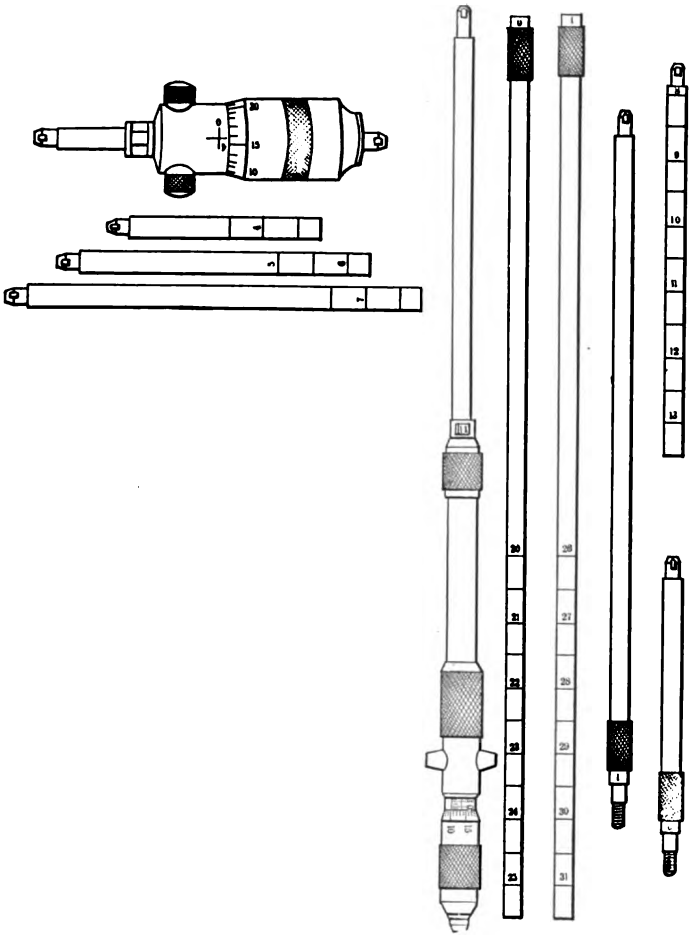

FIG. 523c. — Inside Micrometers.

The method of using the micrometer caliper is as follows: Turn the thimble until the micrometer screw (spindle) touches the anvil, and note the force required to bring the zero line of the thimble in line with the zero line of the barrel (sleeve); in the taking of fairly correct measurements it will be necessary for the student to bring the micrometer screw against the work with this same amount of force. The thimble is now turned until the screw recedes a somewhat greater distance from the anvil than

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the thickness of the piece to be measured. Placing the piece between the anvil and the end of the screw, the thimble is slowly revolved until, by the sense of touch, the operator notes that the micrometer screw (spindle) is in contact with the work; the reading is then taken. Many micrometers are fitted with some sort of a locking device which prevents the accidental rotation of the screw. In addition to the locking device some micrometers have a *ratchet stop* whereby, if more than a certain degree of pressure is exerted, the ratchet slips by the pawl and prevents the turning of the screw; this is convenient for the rapid measurement of a number of similar pieces as they are all subjected to the same degree of pressure. Fig. 523*c* shows a set of inside micrometers. Such micrometers are designed for making internal measurements and may be used for measuring rings, cylinder diameters, setting calipers, comparing gages, measuring parallel surfaces and work of a similar character. Inside micrometers generally consist of a micrometer head, carrying the micrometer screw, thimble — graduated to read thousandths — and four or more extension rods. The rods are provided with a hardened steel adjustable anvil in the ends, which permits adjusting for wear. A small binding screw locks the rod, when set, to any one of the series of lines, — the rods being marked in half-inch or inch divisions and set to a similar line on a projection of the barrel.

524. The Micrometer Caliper Square. By the use of this tool the operator is enabled to enlarge or decrease work one or more thousandths of an inch from that calipered; this tool embodies some of the more important features of both the first-class caliper square and the micrometer caliper. It may be used as a caliper square or a micrometer of large scope and quick adjustment, or both. As a tool it is less accurate than the micrometer caliper on account of the fact that the "personal equation" enters into most of its adjustments, as the settings depend largely upon the ability of the operator to see accurately. When set to standard gages this inaccuracy, of course, disappears. The jaws are hardened and ground and open the length of the graduations on the beam (generally 4″, though made in any length), one side of which is graduated in 40ths and the other in 64ths of an inch. In using this instrument the first setting is made by making the graduation mark on the movable jaw coincide with that division nearest the size desired; it is then clamped in position. The

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next step is to loosen the binding screw on the clasp carrying the micrometer nut, and to turn the nut until the zero mark coincides with the graduation line on the clasp; this clasp is then clamped in position and the clamp on the movable jaw loosened; the tool is now ready for use. When taking a measurement the nut is turned while the operator counts the thousandths, adding to or

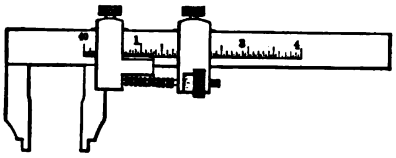

FIG. 524. — Micrometer Caliper Square.

taking from the division shown on the beam at the start as desired. This tool forms an excellent substitute for use in duplicating work when the number of pieces to be finished does not warrant the expense of fixed gages.

525. The Vernier and Its Use. The following description is taken from the catalog of Brown & Sharpe and will, no doubt, prove of value in learning the use of the vernier; its application is general.

"On the bar of the instrument is a line of inches numbered 0, 1, 2, etc., each being divided into ten parts and each tenth into four parts, making forty divisions to the inch. On the

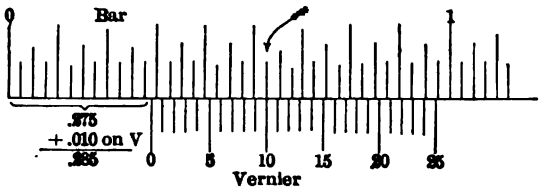

FIG. 525. — Vernier Reading.

sliding jaw is a line of divisions (called a vernier from the inventor's name) of twenty-five parts numbered 0, 5, 10, 15, 20, 25. (Fig. 525.) The twenty-five parts on the vernier correspond, in extreme length, with twenty-four parts or twenty-four fortieths of the bar; consequently, each division on the vernier is smaller than each division on the bar by one thousandth part of an

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inch (.001). If the sliding jaw of the caliper is pushed up to the other, so that the line marked zero (0) on the vernier corresponds with that marked zero on the bar, then the next two lines to the right differ from each other by one-thousandth part of an inch (.001), and so the difference will continue to increase one-thousandth of an inch for each division, until they again correspond at the line marked 25 on the vernier. To read the distance the caliper may be open: commence by noting how many inches, tenths and parts of tenths the zero point on the vernier has been moved from the zero point on the bar. Now count upon the vernier the number of divisions until one is found which coincides with one on the bar, which will be the number of thousandths to be added to the distance read off on the bar. The best way of expressing the value of the divisions on the bar is to call the tenths one-hundred thousandths (.100), and the fourths of tenths, or fortieths, twenty-five thousandths (.025). Referring to the cut (Fig. 525) it will be seen that the jaw is open two-tenths and three-quarters, which is equal to two hundred and seventy-five thousandths (.275). Now suppose the vernier was moved to the right so that the tenth division should coincide with the next one on the scale—which will make ten-thousandths (.010) more to be added to two hundred and seventy-five thousandths (.275), making the jaws open two hundred and eighty-five thousandths (.285).

526. The Vernier Calipers. The vernier caliper is so called because its readings are taken by means of a vernier instead of

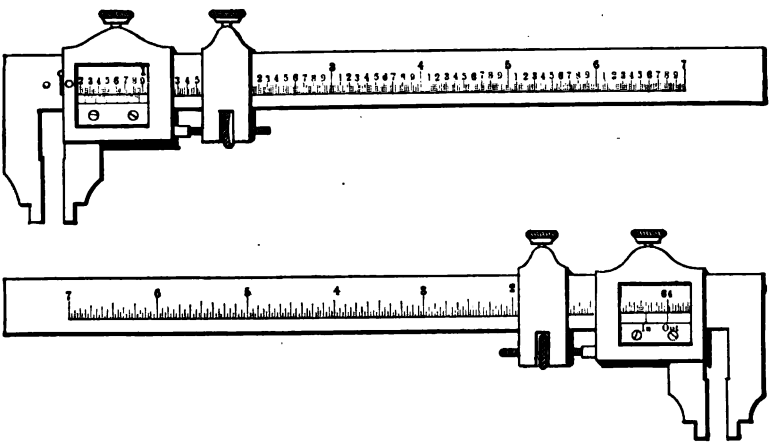

FIG. 526. — Vernier Calipers.

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by means of a micrometer nut. It is similar in almost every respect (except in the method of reading its adjustment) to the micrometer caliper square. When either of these tools has its first setting made by the use of a standard gage, the "personal equation" becomes almost nil, and the accuracy then equals that of the micrometer caliper. The jaws on both the micrometer caliper square and the vernier caliper are so made that internal as well as external measurements may be taken. Vernier calipers may be purchased with beams 24″ long if so desired.

527. The Straight-edge. The straight-edge may be termed a tool for angular measurement as it is used for measuring angles of 180 degrees; *i.e.* for testing the truth and accuracy of an edge

FIG. 527*a*. — Plain Straight-edge.

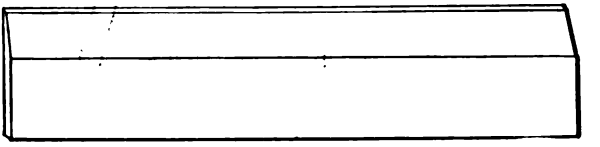

FIG. 527*b*. — Beveled Straight-edge.

FIG. 527*c*. — Knife-edge Straight-edges.

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or plane surface. This is done by placing the tool on the surface and noticing that the light comes through the low places. Straight-edges are made in three different cross-sections and edges; namely, the square edge, the bevel edge and the knife edge, the latter being the most accurate. Straight-edges are generally carefully hardened on the edges and accurately ground by special machines for straightness and parallelism.

528. The Bevel Protractor. The bevel protractor is used by machinists for making angular measurements. As most of these measurements are made between surfaces this protractor is designed to obtain the desired result by a combination of line

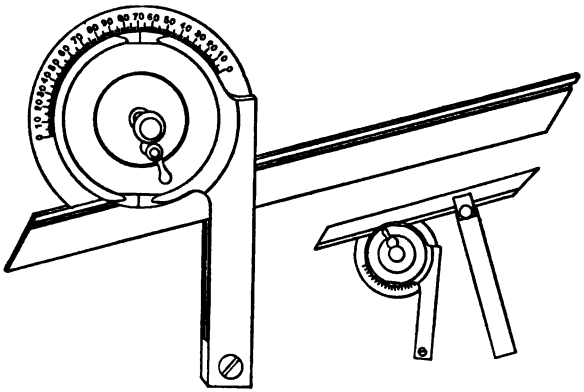

FIG. 528*a*. — Universal Bevel Protractor.

and end measurements. Its essential features are: a *graduated circle* or portion of a circle, in some combination with two *straight-edges*, and a *clamping device* for retaining the relative position of the straight-edges after a setting has been made. Bevel protractors may be purchased in a variety of styles and shapes, according to the ideas of the manufacturers. A common form of bevel protractor has a graduated disc attached to one straight-edge, while the other straight-edge carries the indicator, or zero line, and the clamping device. One straight-edge is called the stock and the other the blade. The blade is from 7″ to 12″ long, while the stock is 4″ long, and both are made from sheet steel. The disc is graduated in degrees from 0 to 90 each way, and rotates the entire circle on a central stud inside the case. The blade (clamped by an eccentric stud against the edge of the disc) may

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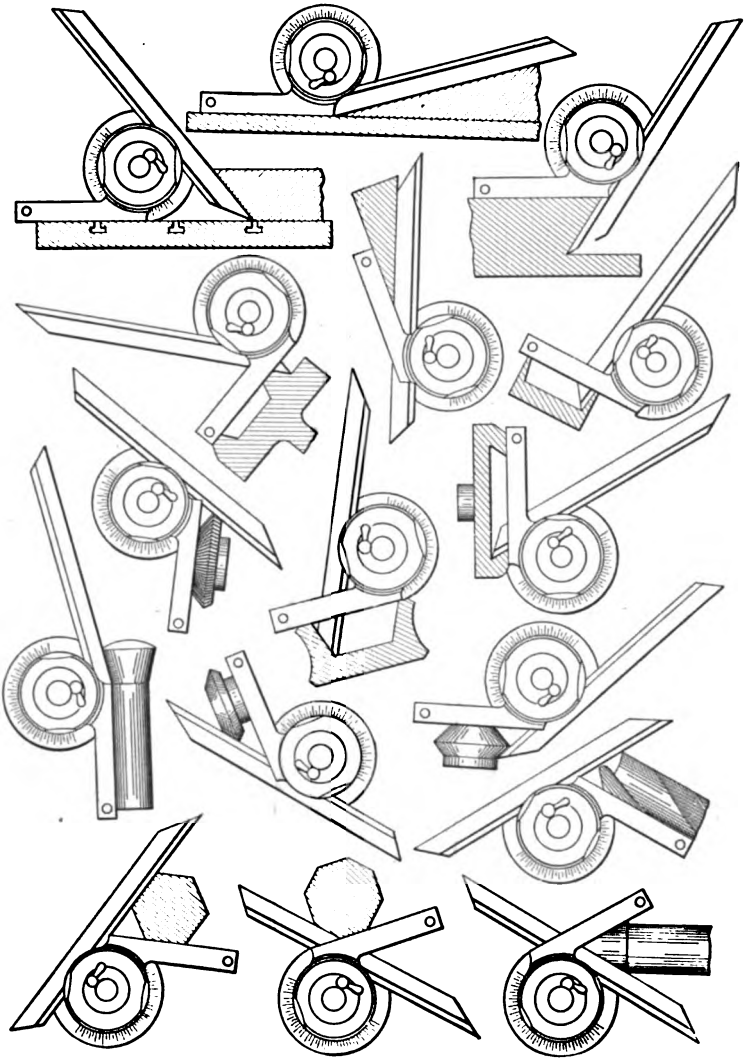

FIG. 528*b*. — Methods of Using the Universal Bevel Protractor.

be slipped back and forth its full length, or turned at any angle around the circle and firmly clamped at any point, thus adapting it for work in positions where other protractors cannot be used and thus rendering the common universal bevel (for transferring angles) unnecessary.

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529. Tables. Table of Tapers and Angles, Table of Angles of Geometrical Figures.

TAPERS PER FOOT AND CORRESPONDING ANGLES

Taper per Foot	Included Angle	Angle with Center Line	Taper per Foot	Included Angle	Angle with Center Line
$\frac{1}{8}$″	0° 36′	0° 18′	1 ″	4° 46′	2° 23′
$\frac{1}{4}$″	1° 12′	0° 36′	1½″	7° 09′	3° 35′
$\frac{5}{16}$″	1° 30′	0° 45′	1¾″	8° 20′	4° 10′
$\frac{3}{8}$″	1° 47′	0° 54′	2 ″	9° 31′	4° 46′
$\frac{7}{16}$″	2° 05′	1° 02′	2½″	11° 54′	5° 57′
$\frac{1}{2}$″	2° 23′	1° 12′	3 ″	14° 15′	7° 08′
$\frac{5}{8}$″	2° 59′	1° 30′	3½″	16° 36′	8° 18′
$\frac{3}{4}$″	3° 35′	1° 47′	4 ″	18° 55′	9° 28′
$\frac{7}{8}$″	4° 10′	2° 05′	5 ″	22° 37′	11″ 18′
$1\frac{1}{16}$″	4° 28′	2° 14′	6 ″	26° 34′	13″ 17′

FIG 529*a*.

TABLE FOR DIVIDING CIRCLES OR LAYING OUT GEOMETRICAL FIGURES

See FIG. 529*c*

No. of Sides	Included Angle	Angles at Center of Circles	Angles for Sides of Figures
3	120°	30°	30°
4	90°	45°	45°
5	72°	18°, 54°	36°, 72°
6	60°	30°	30°
8	45°	45°	22° 30′
10	36°	54°, 18°	18°, 54°
12	30°	60°	15°, 45°
14	25° 43′	64° 17′, 38° 34′, 12° 51′	12° 51′, 38° 34′, 64° 17′
16	22° 30′	67° 30′, 45°	11° 15′, 33° 45′
18	20°	70°, 50°, 30°, 10°	10°, 30°, 50°, 70°
20	18°	72°, 54°	9°, 27°, 45°
24	15°	75°, 60°, 45°	7° 30′, 22° 30, 37° 30′

FIG. 529*b*.

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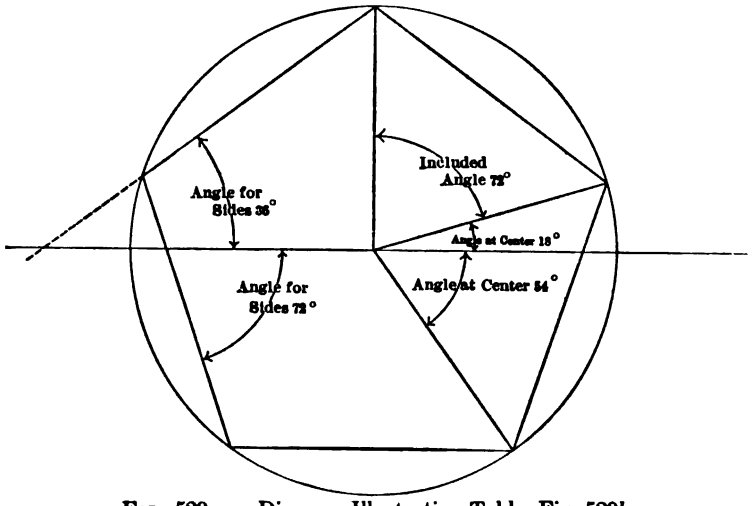

FIG. 529c. — Diagram Illustrating Table, Fig. 529b.

GAGES

531. Classification. Gages for linear dimensions may be divided into dimensional and numbered gages, according to whether they measure a portion of the unit length or express a size by some arbitrary letter or number.

DIMENSIONAL GAGES

541. Test and Reference Gages. Test or reference gages are used chiefly to test the accuracy of other instruments and gages,

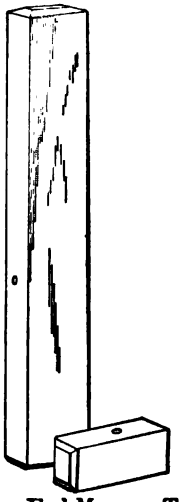

FIG. 541. — End Measure Test Pieces.

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and vary in form in accordance with the maker's ideas. Standard end measures are made either circular or rectangular in section, with the end surfaces parallel and standard within a limit of accuracy of $\frac{1}{50000}$ of an inch. They are accurate subdivisions of the Imperial Yard and are valuable for determining the accuracy of micrometers, slide or beam gages and "snap" gages. Reference discs are shaped like a silver dollar, their circular form making them very convenient for setting calipers. Very accurate measurements may be made with this form of gage as a very delicate contact is obtained, since the gage and piece are only in line contact with each other.

542. Standard Cylindrical Gages. This class of working gages is recommended for the most accurate work, and possesses large

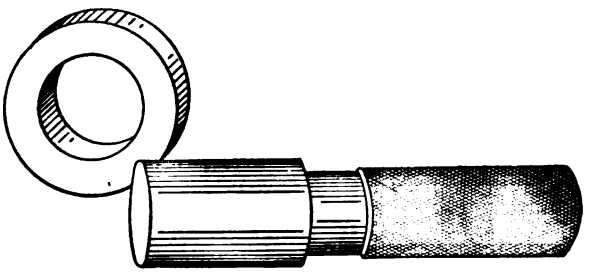

FIG. 542. — Cylindrical Gage and Plug.

wearing surfaces which are hardened, ground and lapped accurately to size; and on account of the warranted accuracy to $\frac{1}{50000}$ of an inch the gages are interchangeable. They are made for both internal and external measurements.

543. Standard Caliper Gages. In the smaller sizes of this gage the external gage is at one end and the internal gage at the other. In construction they are light, rigid and are intended for general shop work. Pratt & Whitney state that it has been clearly demonstrated and proved conclusively that the limit of delicacy of touch in regard to calipering or duplicating parts required to be interchangeable is about $\frac{1}{40000}$ of an inch, and in no other gage is this minute difference so perceptible as with a "snap" (caliper) gage having parallel jaws, hardened, ground and polished, thus making this an available practical "instrument of precision," necessary in every machine shop where interchangeable work is demanded.

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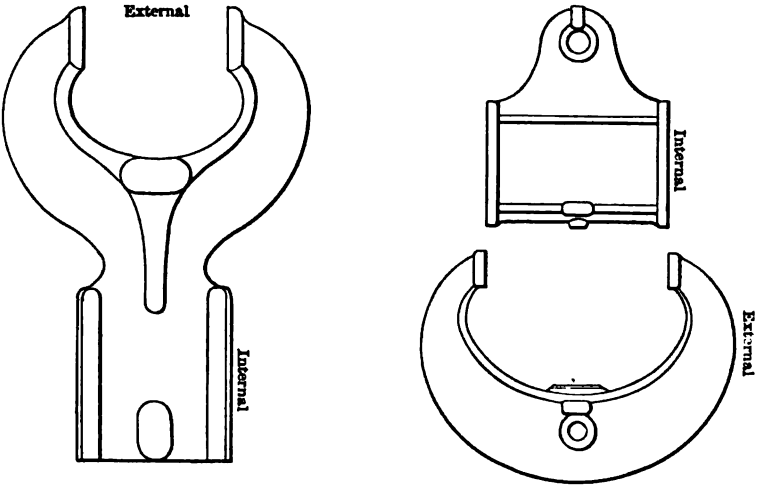

Fig. 543. — Standard Caliper Gages.

544. Limit Gages. Limit gages are used primarily as time-savers to avoid the waste of time in finishing parts unduly accu-

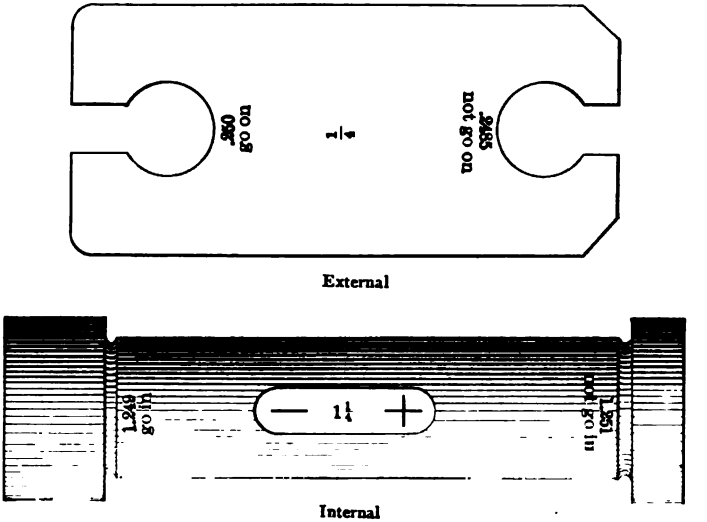

Fig. 544a. — Standard Limit Gages.

rate, still having them accurate enough to meet all the demands of interchangeable manufacture. While other gages give the

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exact size, no knowledge is had as to the exact amount the piece is "out." A limit gage is in fact two gages; thus in the external form one, the "go on" is intended to slip over the piece; the other, the "not go on," one, not to slip over it, the limit or difference in size between the two varying according to the nature of the work. Such gages are widely used where the accurate and economical production of duplicate parts is essential; for by their use the time consumed in testing and gaging is reduced to a minimum, while the parts are still finished accurately enough to have them go together sufficiently well to obviate the necessity

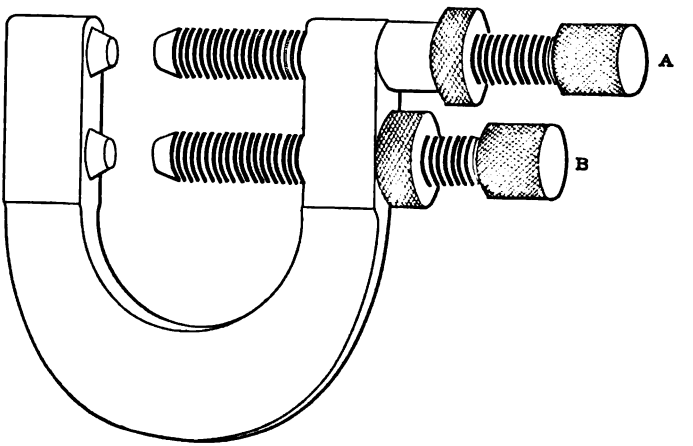

FIG. 544*b*. — Adjustable Limit Gages.

of further fitting. For the limits allowed and the standard limits for limit gages the reader is referred to the tables and data on "Limits for Limit Gages," Section 788, Chapter 7, "Bench and Vise Work."

NUMBERED GAGES

551. Criticism. According to the best authorities, a properly designed, arbitrary (numbered or lettered) gage should have the divisions increase by a regular geometric progression; however, this is not the case with the gages now in use. For several reasons intelligent men look forward to the time when all arbitrary gages will be abolished and when all dimensions will be given in fractions of the unit length. Trautwine makes the

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following pertinent remarks relative to this subject: "No trade stupidity is more thoroughly senseless than the adherence to the various Birmingham, Lancashire, etc., gages instead of at once denoting the thickness and diameter of sheets, wire, etc., by the parts of an inch as has been long suggested. To avoid mistakes that are very apt to occur from the number of gages in use, and from the absurd practice of applying the same gage number to different metals in different towns, it is best to ignore them all and in giving orders to define the diameter of wire and the thickness of sheet metal by parts of an inch."

These arbitrary gages are used to designate the sizes of sheet metal, wire, drill rods, screws, etc., and are made in two different ways; the notched gage is intended to push over the material measured, while with the triangular slotted gage the material (usually of circular cross-section) is pushed into the slot until it touches both sides, when the division at the point of contact gives the gage number.

In Section 558 will be found tables giving the decimal equivalents of an inch, corresponding to the various sheet metal, wire, drill and screw gages in common use.

552. The United States Standard Gage. The United States standard gage was established by an Act of Congress in 1893; it is used by the Government in determining the taxes and duties levied on sheet iron, plate iron and steel, and by some American rolling mills for the above and American planished iron.

553. The American or Brown & Sharpe Gage. This gage is used almost exclusively for sheet brass, sheet aluminum, sheet German silver, brass wire, brazed brass tubing, and German silver wire of American manufacture.

554. The Birmingham or Stubs' Wire Gage. In using Stubs' gages it should be remembered that a difference exists between Stubs' iron wire gage and Stubs' steel wire gage. The Birmingham, the English standard wire and Stubs' wire are the same, and are widely used for sheet iron, sheet steel, sheet copper and seamless tubing of all kinds. Stubs' steel wire gage is used in measuring drawn steel wire or drill rods of Stubs' make.

555. The Washburn & Moen Mfg. Co's Gage. This gage is used almost entirely for gaging the products of this company.

556. The American Twist Drill Gage. This gage is used by American manufacturers for the smaller sizes of twist drills.

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557. The American Screw Gage, and Others. This gage is used almost exclusively for wood and machine screws of iron, steel or brass and designates the size of the unthreaded portion of the shank, regardless of the style of the head.

Among the numerous other gages may be mentioned: The steel music wire gage, the Illinois Zinc Co's zinc gage, the Russia iron gage and the decimal gage.

558. Comparison of Wire, Sheet Metal, and other Gages.

Number of Gage	Dimensions in Decimal Fractions of an Inch							Number of Gage
	Birmingham or Stubs' Iron Wire Gage	American or Brown & Sharpe Gage	Roebling's and Washburn & Moen's Gage	Trenton Iron Co.'s Wire Gage	British Imperial Std. Wire Gage Legal Std. in Gr. Br't'n since Mar. 1, 1884		U. S. Std. Gage for Sheet and Plate Iron and Steel Legal Std. since July 1, 1893	
					Inches	Millimeters		
0000000			.49		.500	12.7	.5	7/0
000000			.46		.464	11.78	.469	6/0
00000			.43	.45	.432	10.97	.438	5/0
0000	.454	.46	.393	.40	.4	10.16	.406	4/0
000	.425	.40964	.362	.36	.372	9.45	.375	3/0
00	.38	.3648	.331	.33	.348	8.84	.344	2/0
0	.34	.32486	.307	.305	.324	8.23	.313	0
1	.3	.2893	.283	.285	.3	7.62	.281	1
2	.28	.25763	.263	.265	.276	7.01	.261	2
3	.259	.22942	.244	.245	.252	6.4	.25	3
4	.238	.20431	.225	.225	.232	5.89	.234	4
5	.22	.18194	.207	.205	.212	5.38	.219	5
6	.203	.16202	.192	.19	.192	1.88	.203	6
7	.18	.14428	.177	.175	.176	4.47	.188	7
8	.165	.12849	.162	.16	.16	4.06	.172	8
9	.148	.11443	.148	.145	.144	3.66	.156	9
10	.134	.10189	.135	.13	.128	3.26	.141	10
11	.12	.09074	.12	.1175	.116	2.95	.125	11
12	.109	.08081	.105	.105	.104	2.64	.109	12
13	.095	.07196	.092	.0925	.092	2.34	.094	13
14	.083	.06408	.08	.08	.08	2.03	.078	14
15	.072	.05707	.072	.07	.072	1.83	.07	15
16	.065	.05082	.063	.061	.064	1.63	.0625	16
17	.058	.04526	.054	.0525	.056	1.42	.0563	17
18	.049	.0403	.047	.045	.048	1.22	.05	18
19	.042	.03589	.041	.04	.04	1.01	.0438	19
20	.035	.03196	.035	.035	.036	.01	.0375	20
21	.032	.02846	.032	.031	.032	.81	.0344	21

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Number of Gage	Dimensions in Decimal Fractions of an Inch							Number of Gage
	Birmingham or Stubs' Iron Wire Gage	American or Brown & Sharpe Gage	Roebling's and Washburn & Moen's Gage	Trenton Iron Co.'s Wire Gage	British Imperial Std. Wire Gage Legal Std. in Gr. Britain since March 1, 1884		U. S. Std. Gage for Sheet and Plate Iron and Steel Legal Std. since July 1, 1893	
					Inches	Millimeters		
22	.028	.02535	.028	.028	.028	.71	.0313	22
23	.025	.02257	.025	.025	.024	.61	.0281	23
24	.022	.0201	.023	.0225	.022	.56	.025	24
25	.02	.0179	.02	.02	.02	.51	.0219	25
26	.018	.01594	.018	.018	.018	.45	.0188	26
27	.016	.01419	.017	.017	.0164	.42	.0172	27
28	.014	.01264	.016	.016	.0148	.38	.0156	28
29	.013	.01126	.015	.015	.0136	.35	.0141	29
30	.012	.01002	.014	.014	.0124	.31	.0125	30
31	.01	.00893	.0135	.013	.0116	.29	.0109	31
32	.009	.00795	.013	.012	.0108	.27	.0101	32
33	.008	.00708	.011	.011	.01	.25	.0094	33
34	.007	.0063	.01	.01	.0092	.23	.0086	34
35	.005	.00561	.0095	.0095	.0084	.21	.0078	35
36	.004	.005	.009	.009	.0076	.19	.007	36

Fig. 558a.

Table of Decimal Equivalents of Screw Gage for Machine and Wood Screws

The difference between consecutive sizes is .01316".

No. of Screw Gage	Size of Number in Decimals	No. of Screw Gage	Size of Number in Decimals	No. of Screw Gage	Size of Number in Decimals
000	.03152	16	.26840	34	.50528
00	.04468	17	.28156	35	.51844
0	.05784	18	.29472	36	.53160
1	.07100	19	.30788	37	.54476
2	.08416	20	.32104	38	.55792
3	.09732	21	.33420	39	.57108
4	.11048	22	.34736	40	.58424
5	.12364	23	.36052	41	.59740
6	.13680	24	.37368	42	.61056
7	.14996	25	.38684	43	.62372
8	.16312	26	.40000	44	.63688
9	.17628	27	.41316	45	.65004
10	.18944	28	.42632	46	.66320
11	.20260	29	.43948	47	.67636
12	.21576	30	.45264	48	.68952
13	.22892	31	.46580	49	.70268
14	.24208	32	.47896	50	.71584
15	.25524	33	.49212		

Fig. 558b.

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DECIMAL EQUIVALENTS OF THE NUMBERS OF TWIST DRILL AND STEEL WIRE GAGE

No.	Size of Number in Decimals	No.	Size of Number in Decimals	No.	Size of Number in Decimals	No.	Size of Number in Decimals
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.02925
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

FIG. 558c.

SMALL TOOLS — VARIOUS GAGES

561. The Screw Pitch Gage. A screw pitch gage is a tool similar in shape to a pocket-knife; its blades are notched to conform with the sections of standard threads so that they will fit standard screws having a certain number of threads per inch. This tool is used to measure the threads of nuts as well as that of screws. On each blade is stamped the number of notches, that is threads per inch, and twice the depth of the thread; this latter amount subtracted from the outside diameter of the screw gives the size for the tap drill.

562. The Center Gage. The center gage is generally a short notched steel rule, similar in shape to the conventional representation of the feathered end of an arrow. It is used in grinding and in setting screw cutting or threading tools. The angles used

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on the standard gage are 60 degrees for the United States standard thread. The four graduations on this gage have the inch divided into 14, 20, 24 and 32 parts, which are convenient in measuring

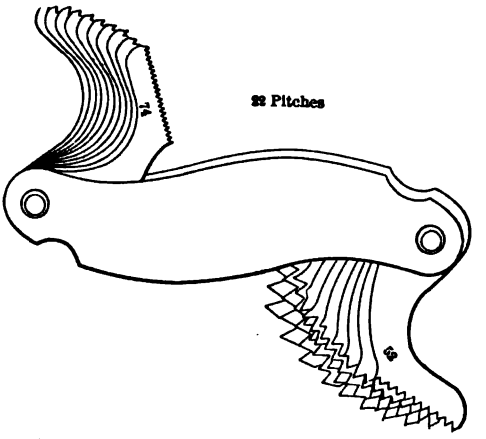

FIG. 561. — Screw Pitch Gage.

the number of threads per inch of ordinary taps and screws; however, all center gages are not graduated and marked alike. Some gages have a table which is used to determine the size of tap drills for "V" threads, giving in thousandths of an inch

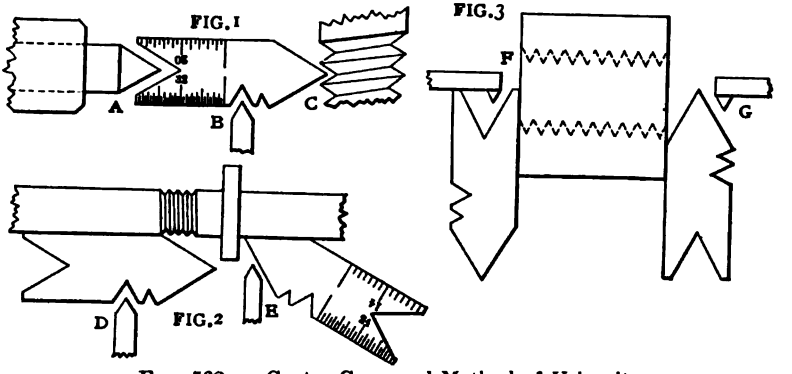

FIG. 562. — Center Gage and Method of Using it.

twice the depth of the thread of the common pitches. This amount subtracted from the diameter of the screw gives the diameter of the tap drill for a "V" thread. Such a table for

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United States standard threads may be made by dividing the constant 1.299 — twice the depth of a thread of a screw that is *one* pitch — by the number of threads for each desired pitch. The use of this gage is illustrated and taken up at length in Section 876.

563. The Depth Gage. A depth gage is a simple tool used for measuring the depth of holes, keyways and recessed parts, as

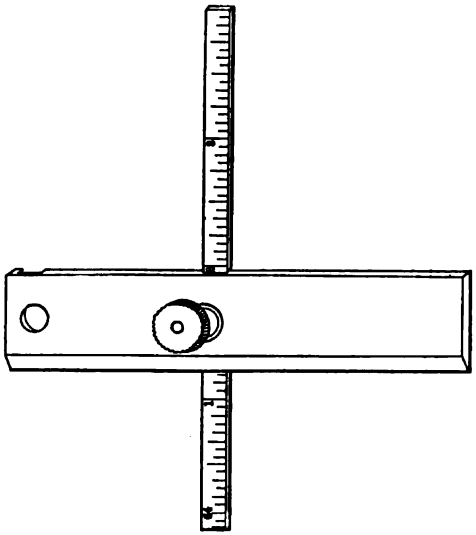

FIG. 563. — Depth Gage.

well as for measuring distances under a shoulder or small projections on a plane surface. The blade or rod generally passes through the head at right angles to it and may be clamped when the setting is made.

564. The Universal Surface Gage. A surface gage is a tool used by machinists for measuring off distances, usually from a given plane surface. It is chiefly used in setting work preparatory to machining it. The principal parts of a universal surface gage are a *solid base* with clamping and adjustment devices, a *post* which may be turned through an arc of 270 degrees, a *swiveled sleeve* carrying a *scriber clasp* which may be swung around the post; a scriber clasp for holding the scriber on the swiveled sleeve and a *scriber* for making the markings. (Fig. 564*a*.)

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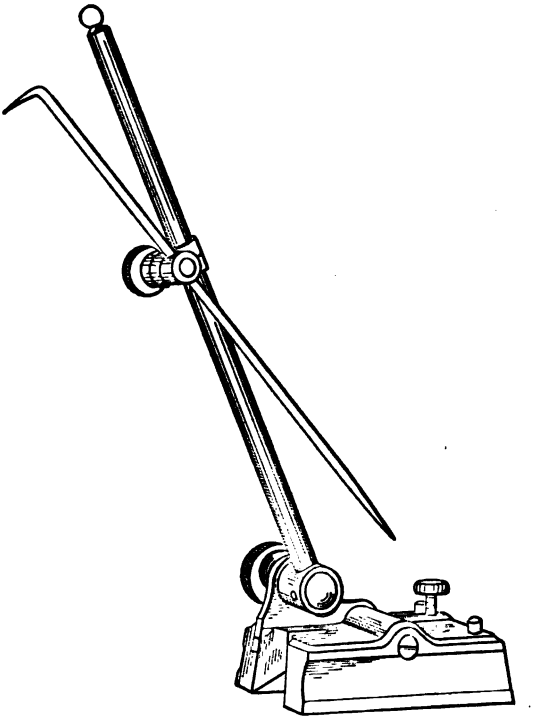

FIG. 564*a*. — Universal Surface Gage.

The base is grooved so that it may be placed on cylindrical surfaces. Minute adjustment may be made after the scriber point is set to the approximate height by turning the knurled adjustment nut, usually located in the base. Fig. 564*b*, page 128, illustrates the use of this tool.

SMALL TOOLS — ORDINARY KIT

571. Arbors or Mandrels. An arbor is generally a shaft or spindle for driving into a bored portion of a piece, the outside of which is to be turned between lathe centers. The term "mandrel" is commonly applied to the same tool. The commercial solid arbor is made of tool steel, hardened and ground, and tapers about $\frac{1}{100}''$ per foot from the smaller end, which is generally exact size, though some are made a trifle under size. The larger end bears the stamp which designates the nominal size, and both

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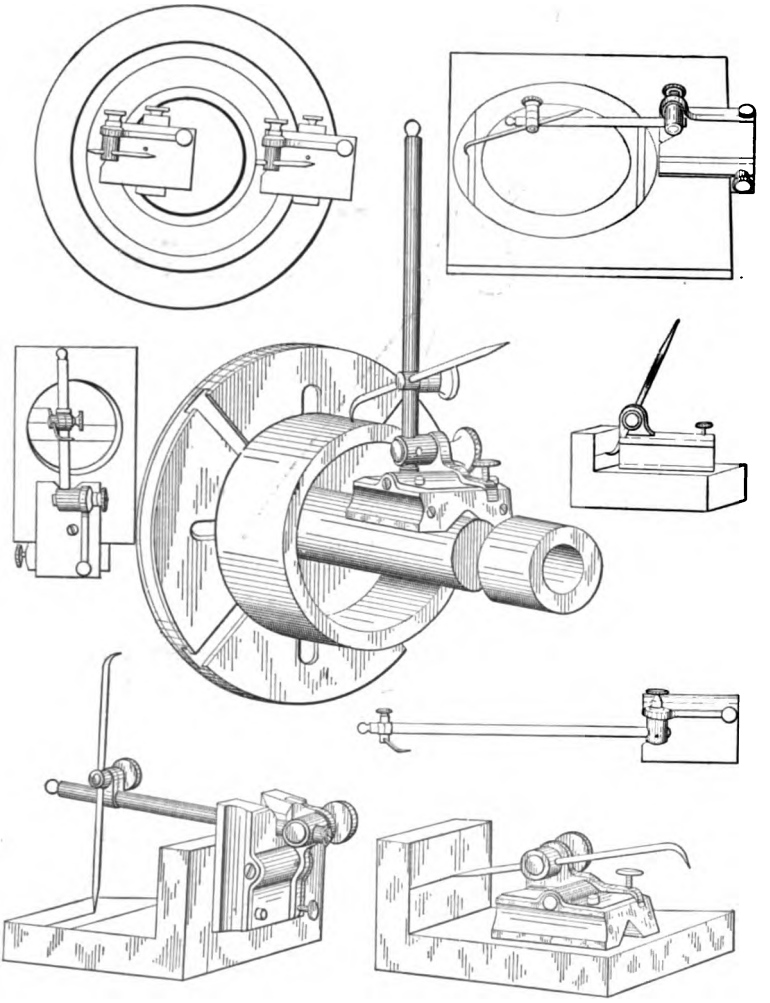

FIG. 564*b*. — Methods of Using the Universal Surface Gage.

FIG. 571*a*. — Hardened and Ground Steel Mandrel.

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ends of such an arbor are turned slightly under size with a flattened portion to receive the dog. The end surfaces are slightly rounded so that the bumping and hammering which they receive will not destroy the truth of the countersunk centers; this class of arbor is designed to hold work reamed by standard reamers.

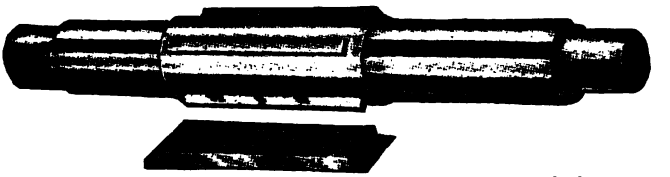

FIG. 571*b*. — Nicholson Expanding Lathe Mandrel.

Expanding arbors or mandrels are generally made with a sleeve and taper, and are designed to hold any work, the bore of which is within their capacity. An arbor should be driven or pressed into the bore just tight enough to prevent slipping; any further forcing tending to distort the piece, thus producing inaccurate work.

572. Reamers. A reamer is a tool designed for truing and making accurate drilled holes which are rarely found to be round and straight. A standard type of reamer consists of a round piece of tool steel, a portion of which contains straight or spiral flutes lengthwise, producing cutting edges, which are hardened and accurately ground to size. The ends of the cutting edges are made slightly rounded or tapered, producing in the reamer a tendency to keep toward the center of the hole. The tapered portion of the cutting edge is sometimes threaded, producing what is called a self-feeding reamer. The end of the shank is

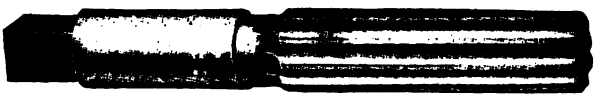

FIG. 572*a*. — Self-feeding Reamer.

provided with a squared portion by means of which the reamer may be turned. Other varieties of reamers that may be mentioned are flat, chucking and shell reamers, for use in turret machinery; roughing and finishing taper reamers for reaming standard taper holes; expanding or adjustable reamers for obtain-

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ing a minute variation in the size of the holes; and center reamers for reaming countersunk centers.

Holes under 1″ in diameter, that are subsequently to be reamed, should be drilled or bored $\frac{1}{64}$″ under size; for holes over 1″ and under 2″ in diameter $\frac{1}{32}$″ of stock is left for the reamer to remove, the holes being made $\frac{1}{32}$″ under size. For very accurate work the reamer should always be operated by hand and the method of securing the alignment of a tap may be successfully used for reaming. A center is inserted in the drill spindle, and this, inserted in the countersink in the end of the reamer, is used to

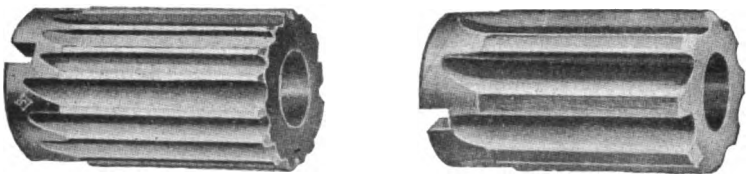

Fig. 572*b*. — Shell Reamers.

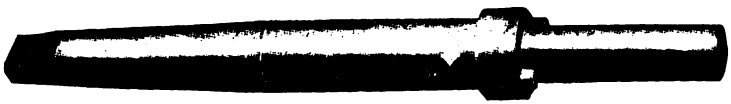

Fig. 572c. — Shell Reamer Arbor.

secure the alignment, the reamer being turned by means of a tap wrench as usual.

573. Calipers. A pair of calipers is a tool with two adjustable legs for taking or transferring measurements. Outside calipers are made with curved legs and, as the name implies, are used for taking outside measurements, while inside calipers have straight legs and are used for inside measurements. Calipers are set to "gage" or to "scale"; they are hardly to be considered as instruments of precision as the setting or the taking of measurements are dependent upon the skill and sense of touch of the operator. In setting calipers to scale, care should be taken to have one leg flush with the end of the scale, adjusting the other leg by means of the thumb nut until it splits the line; as the average thickness of the line is .0025″, an error of this amount is often sufficient to spoil accurate work. In taking measurements the calipers must be placed squarely across the piece, at right angles

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to the portion measured; any deviation — side play — from this position resulting in inaccurate measurements.

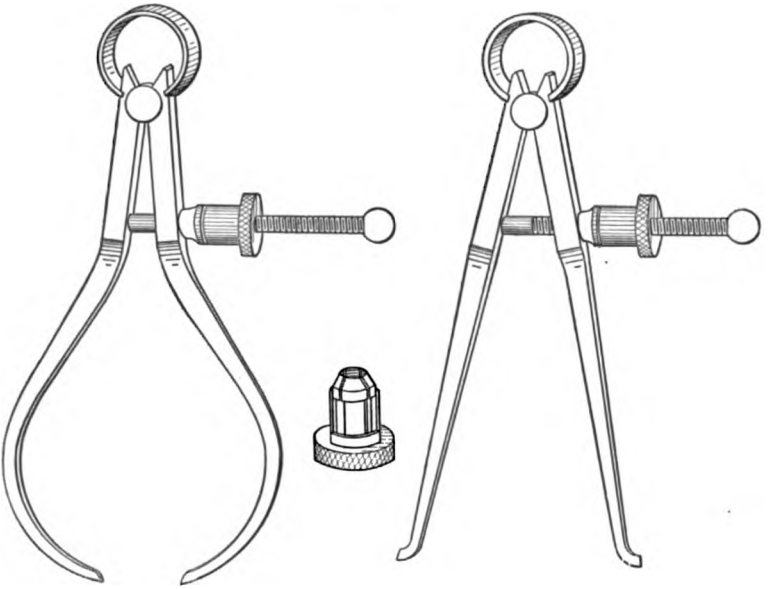

FIG. 573*a*. — Outside and Inside Spring Calipers.

Hermaphrodite calipers have one leg pointed like a divider leg and the other similar to the leg of an inside caliper.

574. Dividers. A pair of dividers is a tool resembling an ordinary pair of compasses and is used by the machinist for dividing and describing various lines and circumferences. The points of the legs are hardened for scratching metal surfaces and the adjustments are made similar to the adjustments of calipers. Dividers are used extensively in laying out drill and lathe work.

575. Scribers. A scriber is a machinist's marker or scratch awl, a standard form of which consists of a cylindrical knurled stock or sleeve with two fine, hardened steel points, one of which is bent at right angles to the axis of the tool.

576. Center Punches. A center punch is a tool similar in size and shape to a nail set, with the point hardened and ground conical. It is used by the machinist for indicating by dots the location of various lines and centers. Before being struck with the hammer, it is held perpendicular to the surface to be marked.

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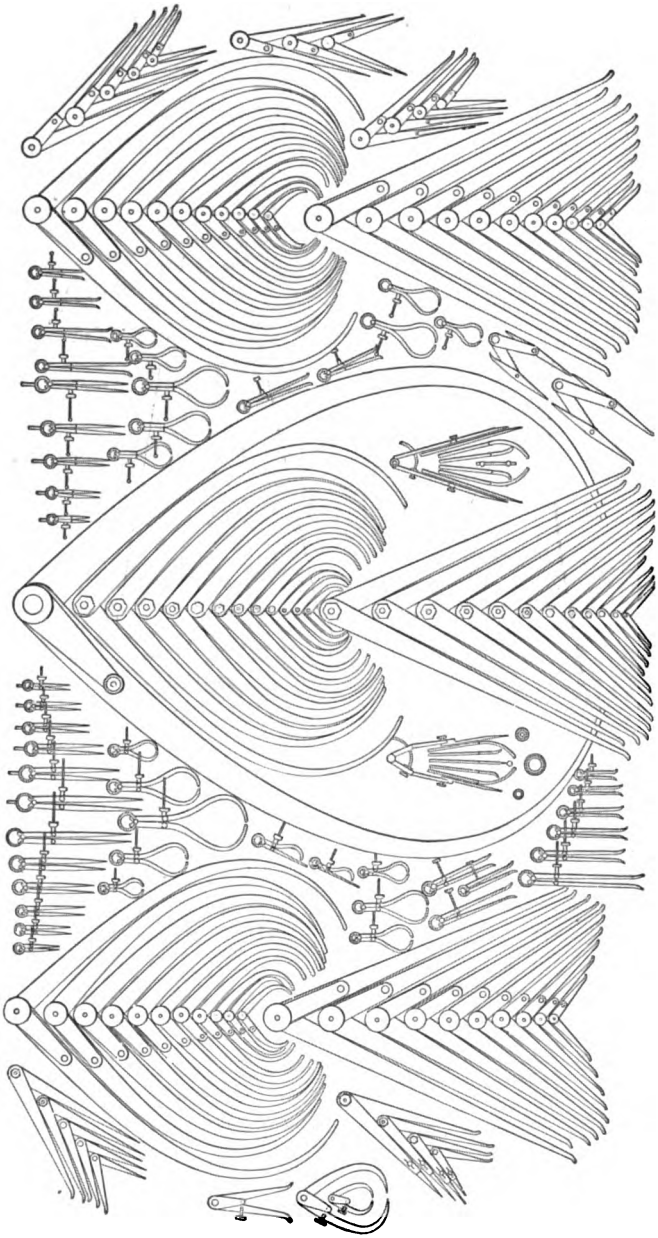

FIG. 573*b*. — A Page of Calipers.

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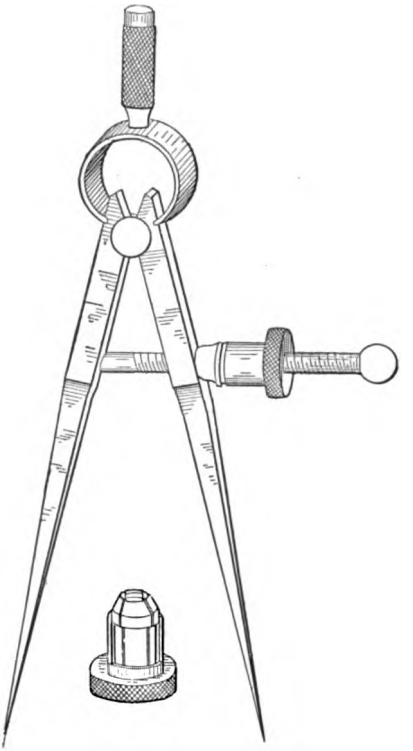

FIG. 574. — Spring Dividers.

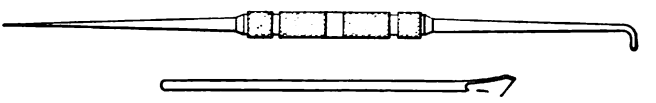

FIG. 575. — Sleeve Scriber.

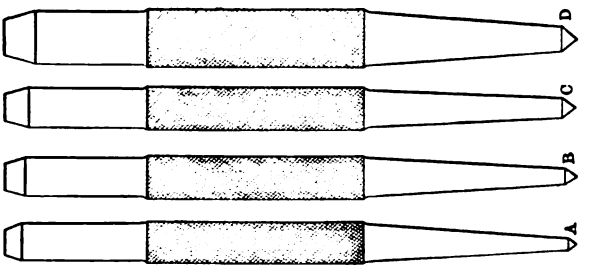

FIG. 576. — Center Punches.

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The location of any mark may be slightly changed by slanting the punch in the direction towards which it is desired to move the mark.

577. Wrenches. Wrenches are tools used by machinists for turning various nuts and screws; they are made in a variety of designs and sizes. Wrenches may be divided into the following general classes:

Movable jaw wrenches, designed for turning different sized nuts; the common monkey wrench being the best example of this class.

Fixed jaw wrenches are drop-forged or cast wrenches, the distance between whose jaws is fixed.

Socket wrenches are T-shaped wrenches, designed for turning bolts or nuts below the surface.

Spanner wrenches are designed for turning cylindrical nuts.

Pipe wrenches with hardened jaws are used for gripping and turning various sized pipe and cylindrical pieces.

Tap and reamer wrenches, as their names indicate, are used for turning taps and reamers; they are made adjustable and with double handles.

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CHAPTER VI

SCREW AND PIN DATA

Screw Parts

611. Nomenclature. It is important for any one who has to do with the manufacture of screws and screw threads to understand fully the exact meaning of the following terms: Pitch, Lead, Threads per inch and Turns per inch.

612. Pitch. In its strictest sense and in the sense in which it should always be used in referring to screw threads, "pitch" is the distance from the center of one thread to the center of the next thread, measured in a line parallel to the axis of the screw. The "threads to the inch" and "thread pitch" are reciprocals of each other (the reciprocal of a number is 1 divided by that number).

613. Lead. The "lead" of a screw is the distance the thread advances in one turn. In a single-threaded screw the lead and pitch are the same; in a double-threaded screw the lead is twice the pitch, while in a triple-threaded screw the lead is three times the pitch.

614. Threads per Inch. The term "threads per inch" means the number of coils to an inch; however, the term threads per inch has nothing whatever to do with the number of separate grooves or windings. The pitch is the reciprocal of the threads per inch.

615. Turns to an Inch. The "turns to an inch" is the number of advances the thread makes in one inch and is the number obtained by dividing one inch by the lead; that is, the reciprocal of the lead of a screw is the turns per inch.

A thread may be triple-threaded, $\frac{1}{8}''$ pitch, $\frac{3}{8}''$ lead, 8 threads to the inch, and have $2\frac{2}{3}$ turns to an inch.

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Standard Taps and Dies

621. Standard Taps. A tap is a hardened steel screw, fluted longitudinally to form cutting edges, and having at the end of its shank a squared portion, over which is fitted the tap wrench by which it is turned. The common forms of taps are the taper, the plug and the bottoming tap; the general characteristics of each may be noted from Fig. 621.

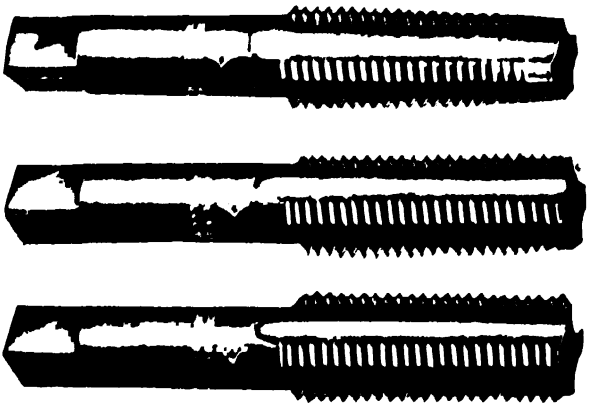

Fig. 621. Hand Taps, Taper, Plug and Bottoming.

The taper tap is used for threading holes which pass clear through the material. Where it is desired to thread a hole that does not run through the piece, the taper tap is used to start the thread, the plug tap to complete it to near the bottom, and should a full thread all the way to the bottom of the hole be required, the bottoming tap must be used.

Taps and dies are made to cut the "standard thread" and are made in sizes given in the table "U. S. Standard Screw-Thread Bolt and Nut Data." (Fig. 671.) For formulas, tap drills and any other data relative to U. S. standard threads, the reader is referred to this table.

622. Machine Screw Taps. Machine screw taps are made with "V" threads and are used for tapping holes for machine

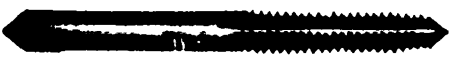

Fig. 622. Machine Screw Tap.

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screws which are generally less than $\frac{1}{4}''$ in diameter. As yet no national standard for machine screw sizes and threads has been established; see Sec. 676. Machine screw taps, like standard hand taps, are made taper, plug and bottoming with the shanks, either the size of the bottom of the thread, or full thread size.

A rough and ready method of determining the size of tap drills for machine screw taps is to insert the point of the tap in a drill gage and select a drill that will make a hole a trifle larger, say $\frac{1}{100}''$. The tables in Section 672 give the decimal equivalents for the nominal sizes of tap drills for machine screw taps.

623. Dies or Screw Plates. Dies or screw plates are hardened, steel-threaded nuts, fluted across the thread so as to form cutting

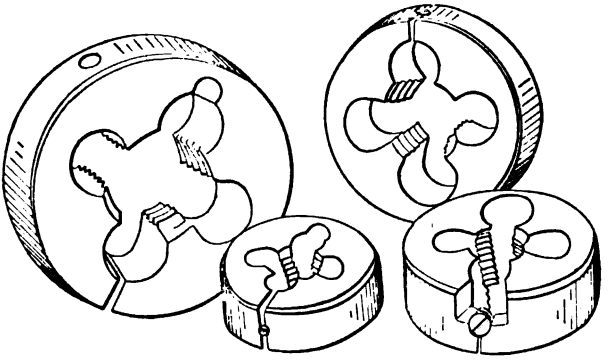

FIG. 623*a*. — Adjustable Dies.

edges, and having such a shape as to be easily fastened in holders called stocks, by which they are turned.

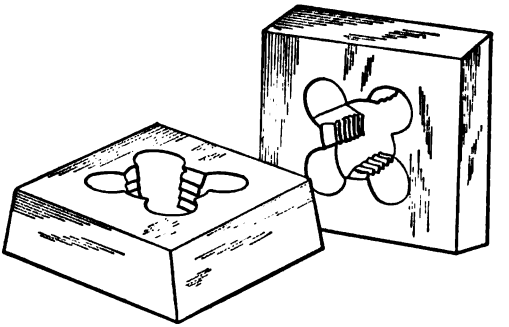

FIG. 623*b*. — Machine or Solid Bolt Dies.

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624. Standard Pipe Taps and Dies. Pipe taps and dies are made to conform with the Briggs' standard of threads for wrought-iron welded tubes, and taper $\frac{3}{4}''$ to the foot. In Section 673 is given a table of standard dimensions of wrought-iron welded pipe according to the Briggs standard, which is now in general use and was formally adopted by the Manufacturers of Wrought-iron Pipe and Boiler Tubes in the United States, at their Pittsburg meeting in 1886.

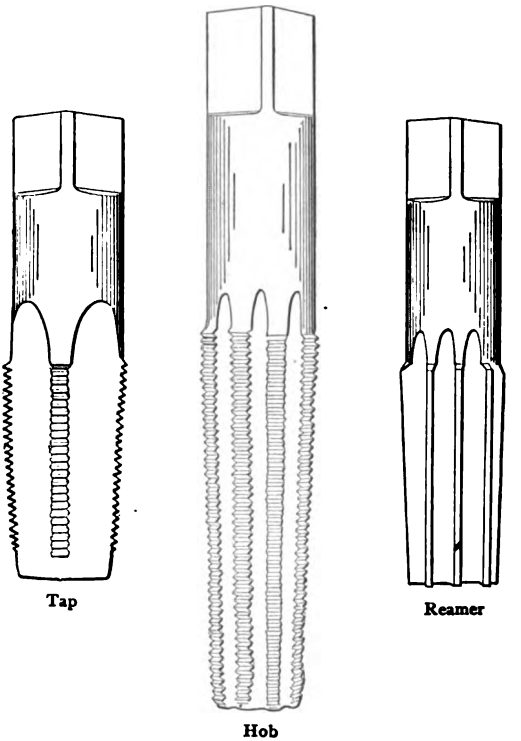

FIG. 624. — Pipe Tap, Hob and Reamer.

SCREWS

631. Machine Screws. Machine, cap, and set screws are made in a variety of sizes and heads. Machine and wood screws are made in sizes corresponding to the American screw gage; the difference between consecutive sizes is .01316″, starting with

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No. 000 which is .03152″, and ending with No. 50, the size of which is .71584.″ The diameter of the screw in inches is obtained by the formula $D = .01316\ (N + 2) + .03153$, where N equal the screw number. In the A.S.M.E. Standard Proportions for

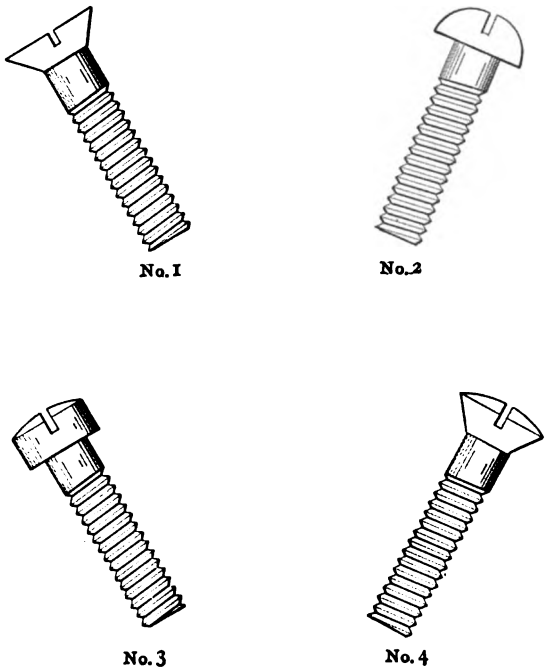

FIG. 631. — Machine Screws. No. 1, Flat Head. No. 2, Round Head. No. 3, Oval Fillister Head. No. 4, Oval Countersunk or French Head.

Machine Screws "The uniform increment between all sizes from .060″ to .190″ is .013″ and between .190″ and including .450″ is .026″. This conforms approximately to the list of screw gage sizes originally established in which the increment is .01316." "This evidently avoids impracticable final decimals and forms a series in which the sizes have a definite relation to each other." "The pitches are a function of the diameter as expressed by the formula, Threads per inch $= \frac{6.5}{D + 0.02}$ and the results are given approximately and in even numbers in order to avoid the use of fractional or odd number threads." The

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angle of the cone of flat-head (countersunk) screws is 76° old style and 82° A.S.M.E. Standard, the sides making angles of 52° old style and 49° A.S.M.E. Standard with the top.

The commoner heads on machine screws are termed flat heads, round heads, flat fillister heads and oval fillister heads. Machine screws are made with "V" or U. S. Standard threads as desired. For further information consult the tables and data in Section 676.

632. Cap Screws. The diameter of cap screws is generally stated in fractions of an inch. They, like machine screws, are made with a variety of heads such as square head, hexagon head, oval fillister head and flat fillister head, flat head, button head and oval countersunk or French head. Cap screws are usually

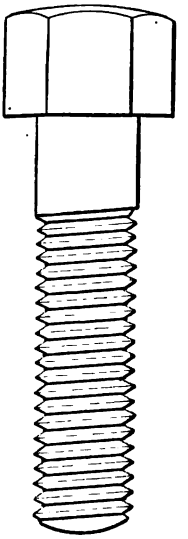

FIG. 632. — Cap Screw.

made with the U. S. Standard thread, and on all screws one inch or less in diameter, and less than four inches long, the threads are cut three quarters of the length; beyond four inches threads are cut half the length. For dimensions of heads and other data consult the table of standard cap and set screws. Section 675.

633 Set Screws. The diameter of set screws, like that of all other bolts and screws except machine screws, is stated in

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fractions of an inch. Set screws may be purchased with the U. S. standard or "V" threads and are always case-hardened, if made of iron, or tempered, if made of steel. They are threaded clear up to the head, which latter, if there be one, is always square. The following terms designate the peculiar characteristics of the commoner set screws: cup point, round point, flat point, cup point headless, round point headless, cone point headless, flat pivot point, round pivot point, hanger set point, cone

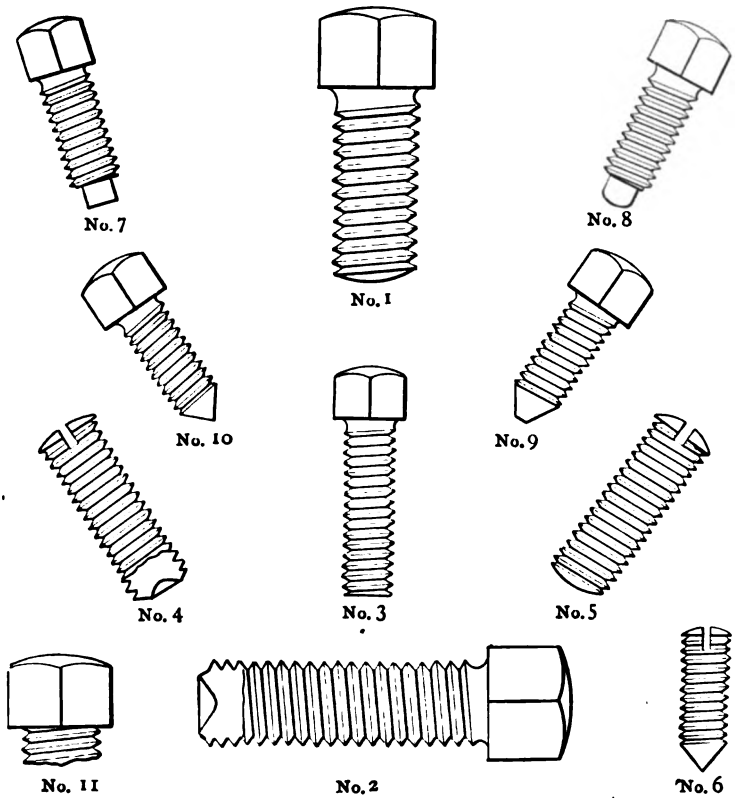

FIG. 633. — Set Screws. No. 1, Regular Round Point. No. 2, Cup Point. No. 3, Flat Point. No. 4, Cup Point Headless. No. 5, Round Point Headless. No. 6, Cone Point Headless. No. 7, Flat Pivot Point. No. 8, Round Pivot Point. No. 9, Hanger Set Point. No. 10, Cone Point. No. 11, Not Necked.

point and not necked. Cup point set screws are regular, all other kinds are special, and no screw which has a head more than $\frac{1}{16}$"

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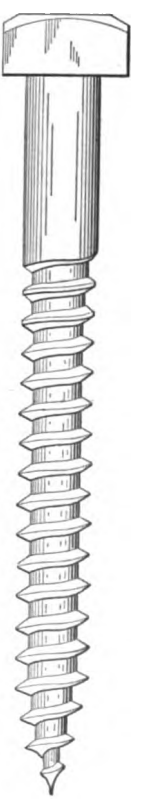
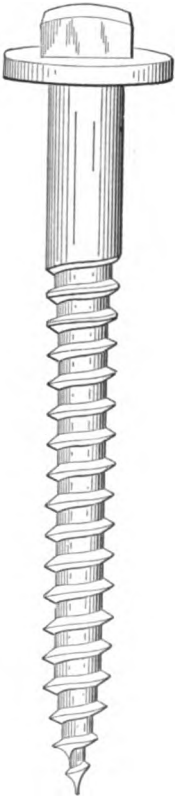
larger than the body is classed as a set screw. See Section 675 for other data regarding set screws.

634. Coach or Lag Screws. Coach or lag screws are large wood screws with a head designed to be turned with a wrench; they are made with either square or washer heads.

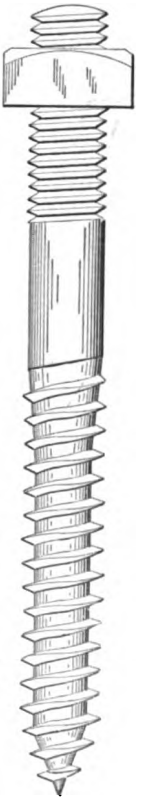


No. 1



No. 2

FIG. 634. — Coach Screws. No. 1, Square Head Gimlet Point. No. 2, Washer Head Gimlet Point.



No. 3

FIG. 635. —Hanger Screw.

635. Hanger Screws. Hanger screws are similar to coach screws with the exception that a nut is provided instead of a head.

BOLTS AND STUDS

641. Machine Bolts. Machine bolts are made U. S. standard with square or hexagon heads and are threaded, on the longer

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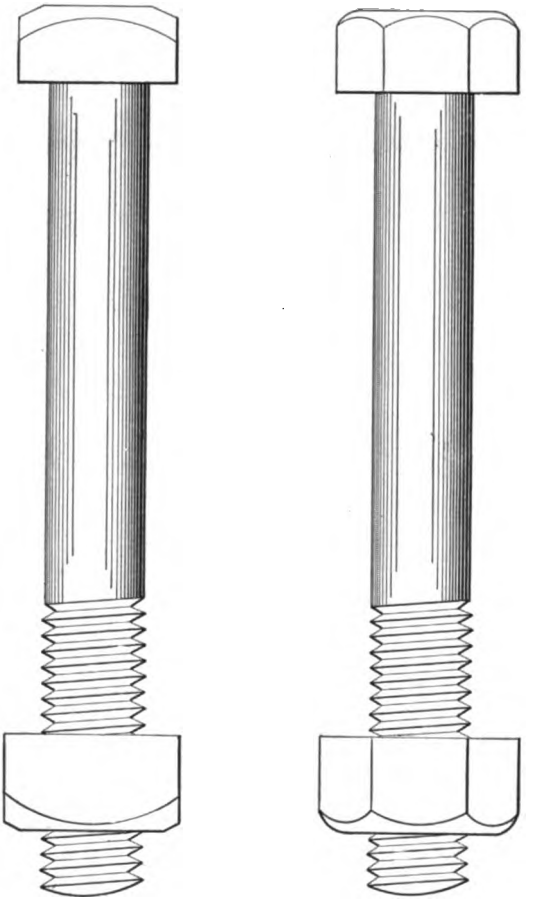
bolts, for a distance equal to three times their diameter. Tap bolts are similar to machine bolts with the exception that they are threaded clear up to the head.



No.1 No.2

FIG. 641. Machine Bolts.— No. 1, Square Head, Square Nut Machine Bolt. No. 2, Hexagon Head, Hexagon Nut Machine Bolt.

642. Coupling Bolts. Coupling bolts are made similar to a hexagon-headed machine bolt, with the exception that the thickness of the head equals the diameter of the bolt and that the

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bolts are machined to size under the head; they are used in the various shaft couplings.

643. Carriage Bolts. Carriage bolts are made with a squared portion directly underneath the head, which latter is never square

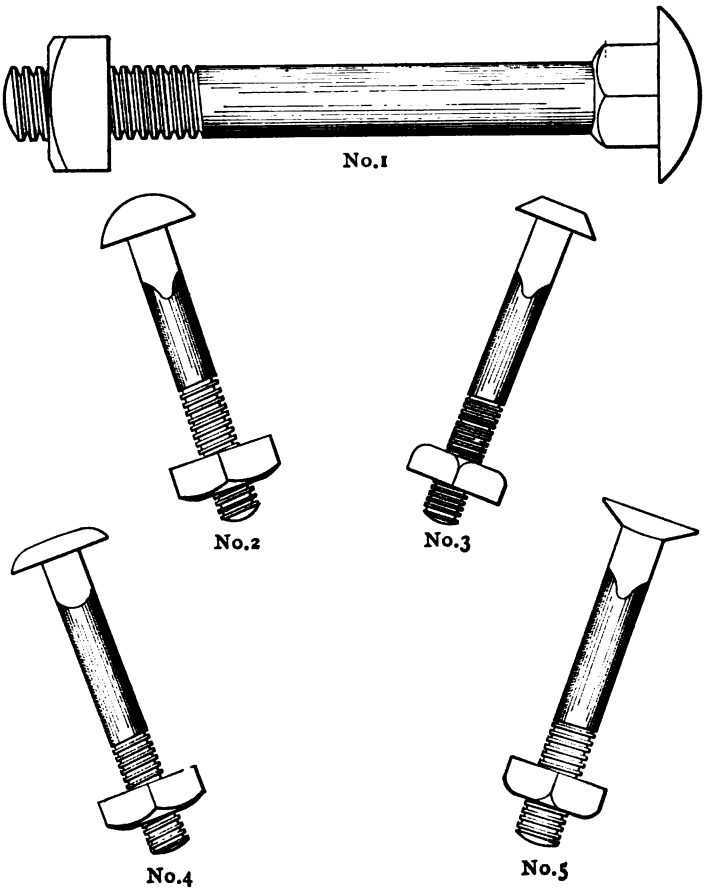

FIG. 643. — Carriage Bolts. No. 1, Common Carriage Bolt. No. 2, Oval Head Philadelphia Eagle Carriage Bolt. No. 3, Bevel Head Philadelphia Eagle Carriage Bolt. No. 4, Bastard Head Philadelphia Eagle Carriage Bolt. No. 5, Countersunk Head Philadelphia Eagle Carriage Bolt.

or hexagon. They are furnished with square nuts and are made with the following heads: common, oval, bevel, bastard and countersunk.

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644. Stove Bolts. Stove bolts are made with flat countersunk or round heads, and are furnished with large, thin square nuts; they are principally used for stove work.

645. Studs. A stud is a piece of steel or iron threaded at both ends with an unthreaded portion in the middle; that portion which is threaded to receive the nut is rounded on the end, while

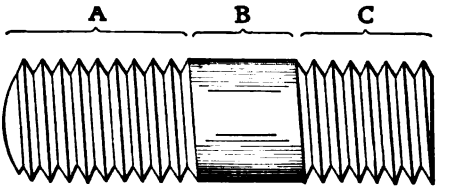

FIG. 645. — Milled Iron Stud.

the portion intended to be screwed into the casting is faced flat; the standard length of the threaded portion being 1½ times the diameter of the screw. Studs are used for bolting heads and flanges to cylinders, or in details where the piece is likely to be removed several times during the life of the machine.

NUTS, RIVETS, COTTERS, ETC.

651. Nuts. A nut is that square- or hexagon-shaped piece of steel with a threaded hole designed to screw on a bolt or stud. Nuts are made in the U. S. standard sizes and may be purchased rough punched, rough threaded, semi-finished, finished and case-hardened.

652. Rivets. Rivets are manufactured of extremely ductile and malleable material and should be able to withstand severe treatment in forging without impairing their strength. They are made with various heads such as flat, round, bevel, cone, machine, globe, countersunk, truss, wheel, oval countersunk and wagon box. See page 146 for Fig. 652.

653. Cotters. A cotter is a split pin with an eye head, designed to be inserted in a drilled hole.

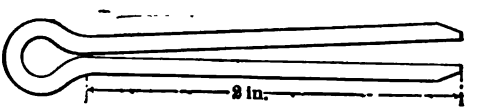

FIG. 653. — Spring Cotter.

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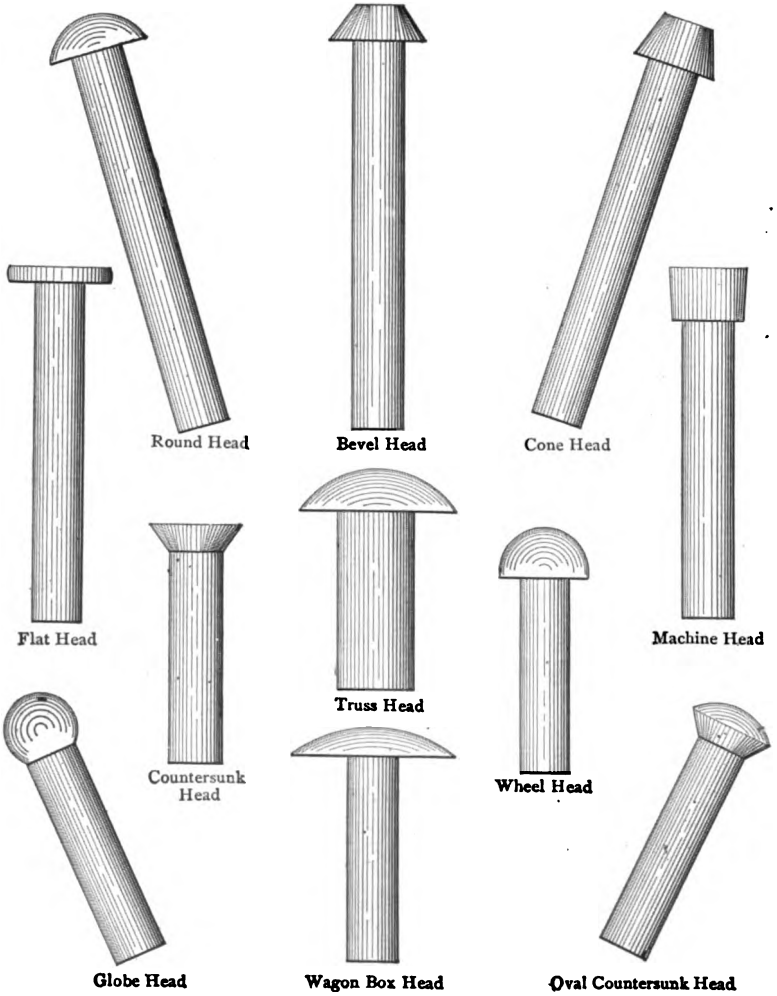

FIG. 652. — Rivets.

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654. Washers. A washer is a thin annular piece of sheet steel designed to fit under the nut or head of a bolt.

655. Burrs. A burr is a special washer designed to fit over the shank of a rivet.

656. Turnbuckles. A turnbuckle is a double-ended sleeve or nut with right and left threads; it is used in guy and tension rods for shortening their length.

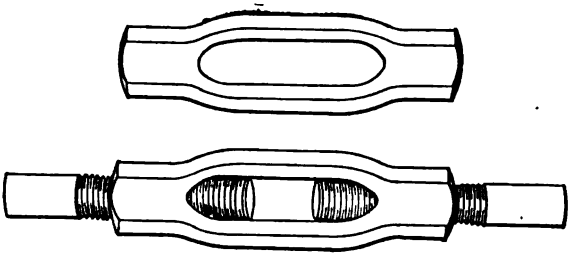

FIG. 656. — Turnbuckles.

PIN DATA

661. Dowel and Taper Pins. Whenever it is necessary in the assembling of machine parts to preserve an alignment, dowels or taper pins are used. Holes are drilled in the pieces, and when the parts are assembled and aligned these holes are reamed with a taper reamer and taper pins fitted into them. The best commercial taper pins are hardened and ground and taper $\frac{1}{4}''$ per foot. Both reamers and pins are so designed that each size "overlaps" the size smaller about $\frac{1}{2}''$ in length; the taper being the same, the advantage thus secured is obvious.

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Tabulated Bolt and Thread Data.

671. U. S. Standard Thread, Bolt and Nut Data.

UNITED STATES STANDARD THREAD, BOLT AND NUT DATA.

No. 1. Double depth of U. S. Standard Thread = 1.299 ÷ Threads per inch.

No. 2. Double Depth of "V" Thread = 1.732 ÷ Threads per inch

No. 3. Distance across Flats, Rough Nut, Hex. or Sqr. = 1½ D + ⅛".

No. 4. Distance across Flats, Finished Nut, Hex. or Sqr. = 1½ D + $\frac{1}{16}$".

No. 5. Distance across Corners, Rough or Finished Hex. Nut = No. 3 or No. 4 X 1.154.

No. 6. Distance across Corners, Rough or Finished Sqr. Nut = No. 3 or No. 4 X 1.414

No. 7. Thickness of Rough Nut = Diameter of Bolt.

No. 8. Thickness of Rough Head = ⅔ X No. 8.

No. 9. Thickness of Finished Nut = Diameter of Bolt — ⅛".

No. 10. Thickness of Finished Head = ⅔ X No. 9 — ⅛".

| DESIGNERS' DATA | | |

672. Tap and Thread Data for Machine Screws.

DECIMAL EQUIVALENTS OF NOMINAL SIZES OF TAP DRILLS FOR MACHINE SCREWS (OLD STYLE STD.)

Diam. In.	Pitch. Thread per In.	Exact Diam. Bot. of Th'd.	Amer. Drill Gage. No. Tap Drill	Diam. Tap Drill in In.	Size Screw Gage	Approx. Sizes in Frac. of In.	Std. No. of Th'ds.	Amer. Drill Gage. No. of Tap Drill	Diam. Tap Drill in In.
1/16	60	.041	57	.0430	0				
1/16	64	.042	56	.0465	1	1/16			
3/32	48	.067	50	.0700	2	5/64	56	46	.0810
3/32	50	.068	50	.0700	3		48	47	.0785
3/32	56	.071	49	.0730	4	7/64	36	43	.0890
3/32	60	.072	48	.0760	5		36	38	.1015
1/8	40	.093	41	.0960	6	9/64	32	37	.1040
1/8	44	.096	40	.0980	7		32	30	.1285
1/8	48	.098	39	.0995	8	5/32	32	29	.1360
5/32	32	.116	31	.1200	9		30	26	.1470
5/32	36	.120	31	.1200	10	3/16	24	26	.1470
5/32	40	.124	30	.1285	11		24	20	.1610
3/16	24	.133	29	.1360	12	7/32	24	19	.1660
3/16	28	.141	27	.1440	13		22	16	.1770
3/16	30	.144	26	.1470	14	1/4	20	14	.1820
3/16	32	.147	25	.1495	15		20	10	.1935
3/16	36	.152	23	.1540	16	17/64	18	7	.2010
7/32	24	.164	19	.1660	17		18	4	.2090
7/32	28	.172	16	.1770	18	19/64	18	1	.2280
7/32	32	.178	14	.1820	19		18	D	.2460
7/32	36	.183	12	.1890	20	5/16	16	E (1/4)	.2500
1/4	18	.178	14	.1820	22		16	H (17/64)	.2660
1/4	20	.185	11	.1910	24	3/8	16	L	.2900
1/4	22	.190	10	.1935	26		16	P (21/64)	.3230
1/4	24	.196	8	.1990	28		14	R (11/32)	.3390
1/4	26	.200	6	.2040	30	7/16	14	T (23/64)	.3580

FIG. 672a.

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672b. Standard Machine Screws. A.S.M.E. Standard.

Basic and Maximum Screw Diameters			Minimum Screw Diameters		
External Diam. and No. Th'ds per In.	Pitch Diameter	Root Diameter	External Diameter	Pitch Diameter	Root Diameter
.060—80	.0519	.0438	.0572	.0505	.0411
.073—72	.064	.0550	.070	.0625	.052
.086—64	.0759	.0657	.0828	.0743	.0624
.099—56	.0874	.0758	.0955	.0857	.0721
.112—48	.0985	.0839	.1082	.0966	.0808
.125—44	.1102	.0955	.1210	.1082	.0910
.138—40	.1218	.1055	.1338	.1197	.1007
.151—36	.1330	.1149	.1466	.1308	.1097
.164—36	.146	.1279	.1596	.1438	.1227
.177—32	.1567	.1364	.1723	.1544	.1307
.190—30	.1684	.1467	.1852	.166	.1407
.216—28	.1928	.1696	.2111	.1903	.1633
.242—24	.2149	.1879	.2368	.2123	.1807
.268—22	.2385	.209	.2626	.2358	.2013
.294—20	.2615	.229	.2884	.2587	.2208
.320—20	.2875	.255	.3144	.2847	.2468
.346—18	.3099	.2738	.3402	.3070	.2649
.372—16	.3314	.2908	.366	.3284	.281
.398—16	.3574	.3168	.392	.3544	.307
.424—14	.3776	.3312	.4178	.3745	.3204
.450—14	.4036	.3572	.4438	.4005	.3464

Fig. 672b.

The pitches are a function of the diameter, as expressed by the formula, threads per inch =

$$\frac{6.5}{D + 0.02}$$

and the results are given approximately and in even numbers in order to avoid the use of fractional or odd number threads.

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673. Standard Dimensions of Wrought-iron Welded Pipe.

Diameter of Pipe			Thickness of the Metal, Inches	Diameter of the Tap Drill, Inches	Screwed Ends	
Nominal Inside, Inches	Actual Inside, Inches	Actual Outside, Inches			Number of Threads per Inch	Length of Perfect Th'd, Inches
$\frac{1}{8}$	.270	.405	.068	$\frac{21}{64}$	27	.19
$\frac{1}{4}$	.364	.504	.088	$\frac{29}{64}$	18	.29
$\frac{3}{8}$	.494	.675	.091	$\frac{19}{32}$	18	.30
$\frac{1}{2}$	.623	.840	.109	$\frac{23}{32}$	14	.39
$\frac{3}{4}$	.824	1.050	.113	$\frac{15}{16}$	14	.40
1	1.048	1.315	.134	$1\frac{3}{16}$	$11\frac{1}{2}$	.51
$1\frac{1}{4}$	1.380	1.660	.140	$1\frac{5}{32}$	$11\frac{1}{2}$	.54
$1\frac{1}{2}$	1.610	1.900	.145	$1\frac{23}{32}$	$11\frac{1}{2}$	.55
2	2.067	2.375	.154	$2\frac{3}{16}$	$11\frac{1}{2}$	.58
$2\frac{1}{2}$	2.468	2.875	.204	$2\frac{11}{16}$	8	.89
3	3.067	3.500	.217	$3\frac{5}{16}$	8	.95
$3\frac{1}{2}$	3.548	4.000	.226		8	1.00
4	4.026	4.500	.237		8	1.05
$4\frac{1}{2}$	4.508	5.000	.246		8	1.10
5	5.045	5.563	.259		8	1.16
6	6.065	6.625	.280		8	1.26
7	7.023	7.625	.301		8	1.36
8	7.982	8.625	.322		8	1.46
9	9.000	9.688[1]	.344		8	1.57
10	10.019	10.750	.366		8	1.68

Fig. 673

Note. — Taper of conical ends, 1 in 32 to axis of tube, or a total taper of $\frac{1}{4}''$ per foot.

[1] Changed to 9.625 by Manufacturers of Wrought Iron Pipe and Boiler Tubes.

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674. Table of Decimal Equivalents of an Inch.

The following table (Fig. 674) of decimal equivalents of an inch will prove useful in many instances and is here inserted to assist in the selection of various drills.

Decimal	8ths	16ths	32ds	64ths	Decimal	8ths	16ths	32ds	64ths
.015625				1	.515625				33
.03125			1		.53125			17	
.046875				3	.546875				35
.0625		1			.5625		9		
.078125				5	.578125				37
.09375			3		.59375			19	
.109375				7	.609375				39
.125	1				.625	5			
.140625				9	.640625				41
.15625			5		.65625			21	
.171875				11	.671875				43
.1875		3			.6875		11		
.203125				13	.703125				45
.21875			7		.71875			23	
.234375				15	.734375				47
.25	2				.75	6			
.265625				17	.765625				49
.28125			9		.78125			25	
.296875				19	.796875				51
.3125		5			.8125		13		
.328125				21	.828125				53
.34375			11		.84375			27	
.359375				23	.859375				55
.375	3				.875	7			
.390625				25	.890625				57
.40625			13		.90625			29	
.421875				27	.921875				59
.4375		7			.9375		15		
.453125				29	.953125				61
.46875			15		.96875			31	
.484375				31	.984375				63
.5					One inch	8	16	32	64

FIG. 674.

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675. Standard Set Screws and Cap Screws. U. S. Standard Thread. (Compiled by W. S. Dix.)

	A	B	C	D	E	F	G
Diameter of Screw.....	1/8	5/16	1/4	5/16	3/8	7/16	1/2
Threads per Inch.....	40	24	20	18	16	14	12
Size of Tap Drill (Cast Iron)	No. 43	No. 30	No. 5	17/64	21/64	3/8	27/64

	H	I	J	K	L	M	N
Diameter of Screw.....	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4
Threads per Inch.....	12	11	10	9	8	7	7
Size of Tap Drill (Cast Iron)	31/64	17/32	31/32	49/64	7/8	63/64	1 1/8

	Set Screws			Hexagon-Head Cap Screws			Square Head Cap Screws		
	Short Diam. Head	Long Diam. Head	Lengths (Under Head)	Short Diam. Head	Long Diam. Head	Lengths (Under Head)	Short Diam. Head	Long Diam. Head	Lengths (Under Head)
(C)	1/4	.35	3/4 to 3	7/16	.51	3/4 to 3	3/8	.53	3/4 to 3
(D)	5/16	.44	3/4 to 3 1/4	1/2	.58	3/4 to 3 1/4	7/16	.62	3/4 to 3 1/4
(E)	3/8	.53	3/4 to 3 1/2	9/16	.65	3/4 to 3 1/2	1/2	.71	3/4 to 3 1/2
(F)	7/16	.62	3/4 to 3 3/4	5/8	.72	3/4 to 3 3/4	9/16	.80	3/4 to 3 3/4
(G)	1/2	.71	3/4 to 4	3/4	.87	3/4 to 4	5/8	.89	3/4 to 4
(H)	9/16	.80	3/4 to 4 1/4	13/16	.94	3/4 to 4 1/4	11/16	.98	3/4 to 4 1/4
(I)	5/8	.89	3/4 to 4 1/2	7/8	1.01	1 to 4 1/2	3/4	1.06	1 to 4 1/2
(J)	3/4	1.06	1 to 4 3/4	1	1.15	1 1/4 to 4 3/4	7/8	1.24	1 1/4 to 4 3/4
(K)	7/8	1.24	1 1/4 to 5	1 1/8	1.30	1 1/2 to 5	1 1/8	1.60	1 1/2 to 5
(L)	1	1.42	1 1/2 to 5	1 1/4	1.45	1 3/4 to 5	1 1/4	1.77	1 3/4 to 5
(M)	1 1/8	1.60	1 3/4 to 5	1 3/8	1.59	2 to 5	1 3/8	1.95	2 to 5
(N)	1 1/4	1.77	2 to 5	1 1/2	1.73	2 to 5	1 1/2	2.13	2 1/4 to 5

	Round and Fillister Head Cap Screws		Flat-Head Cap Screws		Button-Head Cap Screws	
	Diam. of Head	Lengths Under Head	Diam. of Head	Lengths Including Head	Diam. of Head	Lengths Under Head
(A)	5/16	3/4 to 2 1/2	1/4	3/4 to 1 3/4	7/32 (.225)	3/4 to 1 3/4
(B)	1/4	3/4 to 2 3/4	3/8	3/4 to 2	5/16	3/4 to 2
(C)	3/8	3/4 to 3	13/32	3/4 to 2 1/4	7/16	3/4 to 2 1/4
(D)	7/16	3/4 to 3 1/4	5/8	3/4 to 2 3/4	9/16	3/4 to 2 1/2
(E)	9/16	3/4 to 3 1/2	3/4	3/4 to 3	5/8	3/4 to 2 3/4
(F)	5/8	3/4 to 3 3/4	13/16	1 to 3	3/4	3/4 to 3
(G)	3/4	3/4 to 4	7/8	1 1/4 to 3	13/16	1 to 3
(H)	13/16	1 to 4 1/4	1	1 1/2 to 3	15/16	1 1/4 to 3
(I)	7/8	1 1/4 to 4 1/2	1 1/8	1 3/4 to 3	1	1 1/2 to 3
(J)	1	1 1/2 to 4 3/4	1 3/8	2 to 3	1 1/4	1 3/4 to 3
(K)	1 1/8	1 3/4 to 5				
(L)	1 1/4	2 to 5				

Fig. 675.

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676. Standard Machine Screw Proportions and Other Data.

TABLE OF STANDARD MACHINE SCREWS. OLD STANDARD. (COMPILED BY W. S. DIX)

No.	Threads per In.	Diam. of Body	Diam. of Flat Head	Diam. of Round Head	Diam. of Fillister Head	Lengths	
						From	To
2	56	.0842	.1631	.1544	.1332	$\frac{3}{16}$	$\frac{1}{2}$
3	48	.0973	.1894	.1786	.1545	$\frac{3}{16}$	$\frac{5}{8}$
4	32, 36, 40	.1105	.2158	.2028	.1747	$\frac{3}{16}$	$\frac{3}{4}$
5	32, 36, 40	.1236	.2421	.2270	.1985	$\frac{3}{16}$	$\frac{7}{8}$
6	30, 32	.1368	.2864	.2512	.2175	$\frac{3}{16}$	1
7	30, 32	.1500	.2947	.2754	.2392	$\frac{1}{4}$	$1\frac{1}{8}$
8	30, 32	.1631	.3210	.2936	.2610	$\frac{1}{4}$	$1\frac{1}{4}$
9	24, 30, 32	.1763	.3474	.3238	.2805	$\frac{1}{4}$	$1\frac{3}{8}$
10	24, 30, 32	.1894	.3737	.3480	.3035	$\frac{1}{4}$	$1\frac{1}{2}$
12	20, 24	.2158	.4263	.3922	.3445	$\frac{3}{8}$	$1\frac{3}{4}$
14	20, 24	.2421	.4790	.4364	.3885	$\frac{3}{8}$	2
16	16, 18, 20	.2684	.5316	.4866	.4300	$\frac{3}{8}$	$2\frac{1}{4}$
18	16, 18	.2947	.5842	.5248	.4710	$\frac{1}{2}$	$2\frac{1}{2}$
20	16, 18	.3210	.6368	.5690	.5200	$\frac{1}{2}$	$2\frac{3}{4}$
22	16, 18	.3474	.6894	.6106	.5557	$\frac{1}{2}$	3
24	14, 16	.3737	.7420	.6522	.6005	$\frac{1}{2}$	3
26	14, 16	.4000	.7420	.6938	.6425	$\frac{3}{4}$	3
28	14, 16	.4263	.7946	.7354	.6920	$\frac{7}{8}$	3
30	14, 16	.4520	.8473	.7770	.7240	1	3

Lengths vary by 16ths, from $\frac{3}{16}$ to $\frac{1}{2}$, by 8ths from $\frac{1}{2}$ to $1\frac{1}{2}$, by 4ths from $1\frac{1}{2}$ to 3.

FIG. 676a.

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A.S.M.E. Standard Machine Screw Proportions

Old	New	Outside Diameters			Pitch Diameters			Root Diameters		
No.	Out. Dia. and Thds. P. I.	Minimum	Maximum	Difference	Minimum	Maximum	Difference	Minimum	Maximum	Difference
0	.060—80	.0572	.060	.0028	.0505	.0519	.0014	.0410	.0438	.0028
1	.073—72	.070	.073	.003	.0625	.064	.0015	.052	.055	.0030
2	.086—64	.0828	.086	.0032	.0743	.0759	.0016	.0624	.0657	.0033
3	.099—56	.0955	.099	.0035	.0857	.0874	.0017	.0721	.0758	.0037
4	.112—48	.1082	.112	.0038	.0966	.0985	.0019	.0807	.0849	.0042
5	.125—44	.1210	.125	.0040	.1082	.1102	.0020	.0910	.0955	.0045
6	.138—40	.1338	.138	.0042	.1197	.1218	.0021	.1007	.1055	.0048
7	.151—36	.1466	.151	.0044	.1308	.1330	.0022	.1097	.1149	.0052
8	.164—36	.1596	.164	.0044	.1438	.146	.0022	.1227	.1279	.0052
9	.177—32	.1723	.177	.0047	.1544	.1567	.0023	.1307	.1364	.0057
10	.190—30	.1852	.190	.0048	.166	.1684	.0024	.1407	.1467	.0060
12	.116—28	.2111	.216	.0049	.1904	.1928	.0024	.1633	.1696	.0063
14	.242—24	.2368	.242	.0052	.2123	.2149	.0026	.1808	.1879	.0071
16	.268—22	.2626	.268	.0054	.2358	.2385	.0027	.2014	.209	.0076
18	.294—20	.2884	.294	.0056	.2587	.2615	.0028	.2208	.229	.0082
20	.220—20	.3144	.320	.0056	.2847	.2875	.0028	.2468	.255	.0082
22	.346—18	.3402	.346	.0058	.3070	.3099	.0029	.2649	.2738	.0089
24	.372—16	.366	.372	.0060	.3284	.3314	.0030	.281	.2908	.0098
26	.398—16	.392	.398	.0060	.3544	.3574	.0030	.307	.3168	.0098
28	.424—14	.4178	.424	.0062	.3745	.3776	.0031	.3204	.3312	.0108
30	.450—14	.4438	.450	.0062	.4005	.4036	.0031	.3464	.3572	.0108

Fig. 676*b*.

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SPECIAL SCREWS. A.S.M.E. STANDARD

OLD	NEW	OUTSIDE DIAMETERS			PITCH DIAMETERS			ROOT DIAMETERS		
No.	Out. Dia. and Thds. P. I.	Minimum	Maximum	Difference	Minimum	Maximum	Difference	Minimum	Maximum	Difference
1	.073—64	.0698	.073	.0032	.0613	.0629	.0016	.0494	.0527	.0033
2	.086—56	.0825	.086	.0035	.0727	.0744	.0017	.0591	.0628	.0037
3	.099—48	.0952	.099	.0038	.0836	.0855	.0019	.0677	.0719	.0042
4	.112—40	.1078	.112	.0042	.0937	.0958	.0021	.0747	.0795	.0048
	36	.1076	.112	.0044	.0918	.094	.0022	.0707	.0759	.0052
5	.125—40	.1208	.125	.0042	.1067	.1088	.0021	.0877	.0925	.0048
	36	.1206	.125	.0044	.1048	.107	.0022	.0837	.0889	.0052
6	.138—36	.1336	.138	.0044	.1178	.120	.0022	.0967	.1019	.0052
	32	.1333	.138	.0047	.1154	.1177	.0023	.0917	.0974	.0057
7	.151—32	.1463	.151	.0047	.1284	.1307	.0023	.1047	.1104	.0057
	30	.1462	.151	.0048	.1270	.1294	.0024	.1017	.1077	.0060
8	.164—32	.1593	.164	.0047	.1414	.1437	.0023	.1177	.1234	.0057
	30	.1592	.164	.0048	.1400	.1424	.0024	.1147	.1207	.0060
9	.177—30	.1722	.177	.0048	.1529	.1553	.0024	.1277	.1337	.0060
	24	.1718	.177	.0052	.1473	.1499	.0026	.1158	.1229	.0071
10	.190—32	.1853	.190	.0047	.1674	.1697	.0023	.1437	.1494	.0057
	24	.1848	.190	.0052	.1603	.1629	.0026	.1288	.1359	.0071
12	.216—24	.2108	.216	.0052	.1863	.1889	.0026	.1548	.1619	.0071
14	.242—20	.2364	.242	.0056	.2067	.2095	.0028	.1688	.1770	.0082
16	.268—20	.2624	.268	.0056	.2327	.2355	.0028	.1948	.203	.0082
18	.294—18	2882	.294	.0058	.255	.2579	.0029	.2129	.2218	.0089
20	.320—18	.3142	.320	.0058	.281	.2839	.0029	.2389	.2478	.0089
22	.346—16	.340	.346	.0060	.3024	.3054	.0030	.255	.2648	.0098
24	.372—18	.3662	.372	.0058	.333	.3359	.0029	.2909	.2998	.0089
26	.398—14	.3918	.398	.0062	.3485	.3516	.0031	.2944	.3052	.0108
28	.424—16	.418	.424	.0060	.3804	.3834	.0030	.333	.3428	.0098
30	.450—16	.444	.450	.0060	.4064	.4094	.0030	.359	.3688	.0098

FIG. 676*b* (*continued*).

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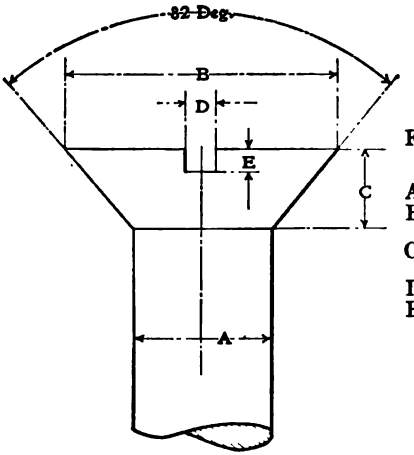

FIG. 676c. FLAT HEAD SCREWS. A.S.M.E. STANDARD

A = Diameter of Body
B = 2A − .008 = Diameter of Head
$C = \frac{A - .008}{1.739}$ = Thickness of Head
D = .173A + .015 = Width of Slot
E = ⅓C = Depth of Slot

A	B	C	D	E
.060	.112	.030	.025	.010
.073	.138	.037	.028	.012
.086	.164	.045	.030	.015
.099	.190	.052	.032	.017
.112	.216	.060	.034	.020
.125	.242	.067	.037	.022
.138	.268	.075	.039	.025
.151	.294	.082	.041	.027
.164	.320	.090	.043	.030
.177	.346	.097	.046	.032
.190	.372	.105	.048	.035
.216	.424	.120	.052	.040
.242	.476	.135	.057	.045
.268	.528	.150	.061	.050
.294	.580	.164	.066	.055
.320	.632	.179	.070	.060
.346	.684	.194	.075	.065
.372	.736	.209	.079	.070
.398	.788	.224	.084	.075
.424	.840	.239	.088	.080
.450	.892	.254	.093	.085

FIG. 676c.

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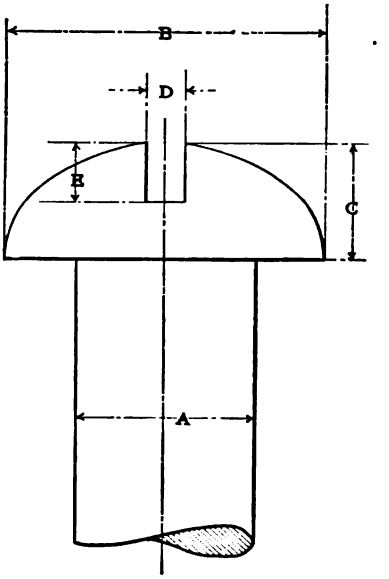

FIG. 676*d*. ROUND HEAD SCREWS. A.S.M.E. STANDARD

A = Diam. of Body
B = 1.85A − .005. = Diam. of Head
C = .7A = Height of Head
D = .173A + .015 = Width of Slot
E = ½C + .01 = Depth of Slot

A	B	C	D	E
.060	.106	.042	.025	.031
.073	.130	.051	.028	.035
.086	.154	.060	.030	.040
.099	.178	.069	.032	.044
.112	.202	.078	.034	.049
.125	.226	.087	.037	.053
.138	.250	.097	.039	.058
.151	.274	.106	.041	.063
.164	.298	.115	.043	.067
.177	.322	.124	.046	.072
.190	.346	.133	.048	.076
.216	.394	.151	.052	.085
.242	.443	.169	.057	.094
.268	.491	.188	.061	.104
.294	.539	.206	.066	.113
.320	.587	.224	.070	.122
.346	.635	.242	.075	.131
.372	.683	.260	.079	.140
.398	.731	.279	.084	.149
.424	.779	.297	.088	.158
.450	.827	.315	.093	.167

FIG. 676*d*.

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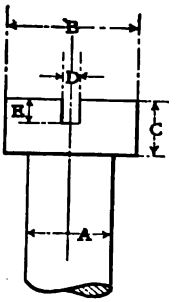
FIG. 676e. FLAT FILLISTER HEAD SCREWS. A.S.M.E. STANDARD

A = Diam. of Body
B = 1.64A − .009 = Diam. of Head
C = 0.66A − .002 = Height of Head
D = 0.173A + .015 = Width of Slot
E = ½C = Depth of Slot



A	B	C	D	E
.060	.0894	.0376	.025	.019
.073	.1107	.0461	.028	.023
.086	.132	.0548	.030	.027
.099	.153	.0633	.032	.032
.112	.1747	.0719	.034	.036
.125	.196	.0805	.037	.040
.138	.217	.0890	.039	.044
.151	.2386	.0976	.041	.049
.164	.2599	.1062	.043	.053
.177	.2813	.1148	.046	.057
.190	.3026	.1234	.048	.062
.216	.3452	.1405	.052	.070
.242	.3879	.1577	.057	.079
.268	.4305	.1748	.061	.087
.294	.4731	.1920	.066	.096
.320	.5158	.2092	.070	.104
.346	.5584	.2263	.075	.113
.372	.601	.2435	.079	.122
.398	.6437	.2606	.084	.130
.424	.6863	.2778	.088	.139
.450	.729	.0295	.093	.147

FIG. 676e.

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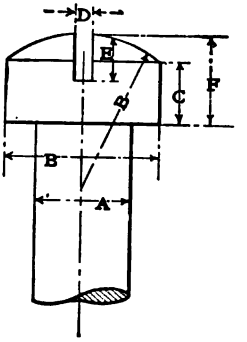
FIG. 676*f*. OVAL FILLISTER HEAD SCREWS. A.S.M.E. STANDARD

A = Diameter of Body
B = 1.64A − .009 = Diam. of Head and Rad. for Oval
C = 0.66A − .002 = Height of Side
D = .173A + .015 = Width of Slot
E = ½F = Depth of Slot
F = .134B + C = Height of Head



A	B	C	D	E	F
.060	.0894	.0376	.025	.025	.0496
.073	.1107	.0461	.028	.030	.0609
.086	.132	.0548	.030	.036	.0725
.099	.153	.0633	.032	.042	.0838
.112	.1747	.0719	.034	.048	.0953
.125	.196	.0805	.037	.053	.1068
.138	.217	.089	.039	.059	.1180
.151	.2386	.0976	.041	.065	.1296
.164	.2599	.1062	.043	.071	.1410
.177	.2813	.1148	.046	.076	.1524
.190	.3026	.1234	.048	.082	.1639
.216	.3452	.1405	.052	.093	.1868
.242	.3879	.1577	.057	.105	.2097
.268	.4305	.1748	.061	.116	.2325
.294	.4731	.192	.066	.128	.2554
.320	.5158	.2092	.070	.140	.2783
.346	.5584	.2263	.075	.150	.3011
.372	.601	.2435	.079	.162	.3240
.398	.6437	.2606	.084	.173	.3469
.424	.6863	.2778	.088	.185	.3698
.450	.729	.295	.093	.196	.3927

FIG. 676*f*.

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CHAPTER VII

BENCH AND VISE WORK

Preliminary Process — Laying Out

711. Laying Out Rectilinear Work. Laying out work may be described as the operation of placing on a casting, forging or partially finished surface such lines as will indicate the location and character of the various operations specified by the drawings. The necessity of laying out all work is apparent when one realizes the amount of time and annoyance that may be saved by it in the detection of errors already inherent in the piece or those due to previous operations.

Laying out consists in designating centers by center punch marks, drawing lines with a surface gage, scriber and dividers on previously coated surfaces, and in tracing irregular forms on them from templets. Permanence is given to many lines and arcs by dotting and chiseling them. In general, laying out should be done on some solid plane surface such as that of a bench block or a plate. The surface coating on which the lines are described may be chalk, powdered chalk and alcohol, copper sulphate — where the surface is free from oil — and any of the various coating paints on the market.

712. Laying Out Cylindrical Work. Cylindrical work is usually placed in V blocks or V chucks while flat pieces are placed directly on the plate. Centers for cored holes or openings are located by fitting a strip of wood across them and driving into this piece of wood at the approximate center a tin tag, made by bending down the corners of a triangular piece of tin, and upon this tag describing the lines and marks which locate the center.

The operation of locating centers on work is one of importance and requires careful attention. Various methods are used, the method depending upon the shape of the piece. Cylindrical pieces, or those whose cross-section is symmetrical, are usually

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centered by one of the following similar methods: centering by dividers, centering by surface gage or centering by hermaphrodite calipers. On the ends of the piece, with a distance somewhat greater or less than half its diameter, four lines or arcs, enclosing a small four-sided figure, are drawn from points on the perimeter. At the center of this figure make the center punch mark, and placing the piece, if possible, between the lathe centers revolve by hand to determine the accuracy of the work; an error of $\frac{1}{32}''$ or more is too great and should be corrected. Dividers may be used for testing the larger pieces. Center punch marks may be crowded over by the slanting of the punch before striking. Cup centers and center squares are often used for centering where square-ended stock is to be had, and centering machines where great numbers of similar pieces are to be centered.

713. Laying Out Drill Work. Chalk the surface to be drilled and determine the position of the hole, locating the exact center by means of a light center punch mark. About this center describe, with the dividers, a circle whose diameter is equal to that of the hole desired. On the circumference of this circle make eight or more light center punch marks at equal intervals. The center punch mark must not be enlarged as it is practically impossible to start the drill in the center of the hole without a good center mark.

In laying off subdivisions of a circle, it is considered good practice to first subdivide the circumference, if possible, into four or six parts and then subdivide these latter divisions; by this means any error that may arise from an incorrect setting of the dividers, where the ordinary method used, is reduced $\frac{1}{8}$ to $\frac{1}{192}$, according as the piece is divided into four or six parts.

Hammering and Sawing

721. Hammering and Peening. Hammers like many another machine-shop tool are used wherever possible; however, they are designed for pounding. Ordinarily they vary in weight from $\frac{1}{2}$ to 2 pounds and are designated as ball-peen, straight-peen and cross-peen, as the shape of the peen varies. The most common of these is the ball-peen hammer, weighing from 1 to $1\frac{3}{4}$ pounds. This hammer is used for all ordinary work; it being especially adapted to riveting and peening, owing to the fact that the

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effect of the blow by the ball is distributed equally in all directions. When a straight or cross-peen hammer is used for this purpose, the effect of the blow is greater in one direction than in the other. The smaller sized hammers are used on light work such as center marking and in die finishing. In using the hammer the handle should be grasped at its thickest portion and never close up to the hammer. Copper, lead and raw-hide hammers are used for striking light blows on finished work where ordinary hammers would dent the surface.

Peening is the process of stretching iron by striking it with the peen of a hammer. Crooked or sprung castings may often be straightened by judicious peening, and tight nuts and collars may be removed by peening, especially when kerosene is poured into the joint to loosen the nut.

722. Hack Sawing. Hack saws are used for a variety of purposes in the machine shop, mainly where any rough cutting operation is to be performed; nevertheless, considerable care must be exercised in their use, for the highly tempered blades are easily broken in unskilled hands. In tightening the saw in the frame, enough tension is given to prevent lateral motion; however, the saw should not be unduly strained. The frame should be lifted slightly on the backward stroke as this stroke is more destructive to the teeth than the forward one. A saw that cramps or sticks should be lifted clear of the kerf before trying again, and never forced. Owing to their hardness hack-saw blades cannot be filed, but they are cheap enough to throw away when dulled. Power hack-saw blades are usually heavier, thicker and longer than those used in the hand frames. The proper adjustment of the feed of the power saw is all that requires especial attention in power sawing. Oil is frequently used advantageously in this operation on the tougher metals, though this is not general practice.

Threading and Tapping

731. Threading. When it is necessary to put a thread or screw on a piece of stock by hand, dies or screw plates are used. These dies are fastened in holders called stocks which, while holding the die, afford handles for turning it. The operation of cutting the thread is a simple one, though care should be taken

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to eliminate any error that would be caused in work by starting the die on crooked. The face of the die should always be perpendicular to the axis of the piece while it is being threaded. Lard oil should be used freely during the operation on wrought iron and steel, and care taken to back off the die after each turn a distance equal to or greater than each forward cut.

732. Tapping. When it is desired to cut an internal thread or screw by hand a tap is used and the operation called tapping. A tap, as we have learned, is a hardened steel screw fluted longitudinally to form cutting edges and having at the end of its shank a squared portion over which fits the tap wrench by which it is turned. The common forms of machinist's hand taps are the taper, the plug and the bottoming. The reader is advised to refer both to the text and to the illustrations in Chapter 6, "Screw and Pin Data," for additional information relative to taps and dies.

Where it is desired to thread a hole that does not run through the piece, a taper tap is used to start the thread and a plug tap to complete it to near the bottom. If a full thread is desired all the way to the bottom of the hole, a bottoming tap is used. Where the holes pass through the material the taper tap alone is used. The same precautions should be used with the tap that were necessary with the die. Care should be taken to start the tap so that its axis coincides with the axis of the hole and to back off the tap after each forward turn, as was the case with the die in ordinary work; after one or two turns the tap should be tested for truth with the try square.

733. Aligning the Tap. As it is of great importance that a tap be started properly, *i.e.*, so that the axis of the tap coincides with the axis of the hole — the following effective method of securing the alignment is submitted for the benefit of those whose experience is limited: Place the work on the table of the drill, place the cutting end of the tap drill in the drill chuck and bring the work into line by inserting the drill in the hole. Bolt in position, insert the tap in the hole for tapping and hold the butt end of the drill, which is pointed, firmly in the center of the tap while it is being turned, with the tap wrench. This method is suggestive of many ways in which the drill and lathe may be used for securing the alignment for the rapid and profitable tapping of small holes. With this method the tap should always be turned by hand.

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Lard oil should be freely used during the operation on wrought iron and steel; cast iron and brass are tapped dry.

734. Depth of Tapped Holes. In ordinary practice, holes to be tapped in cast iron are drilled to a depth of twice the diameter of the screw ($2D$) and tapped to a depth of $1\frac{3}{4}D$, while the screw itself is made to enter the tapped hole $1\frac{1}{2}D$. For wrought iron and machinery steel the proportions are the following: Depth drilled = $1\frac{1}{2}D$, depth tapped = $1\frac{1}{4}D$, depth screw enters = $1D$.

Chipping

741. Chipping and Its Applications. Before the advent of modern machine tools, nearly all finished metal surfaces had first to be chipped and then smoothed up with a file, much after the fashion in which we now remove irregularities on castings. Chipping is still used in places difficult to get at with a machine, in structural work, and when, in the erection of bridges, large machines, etc., some unforeseen obstacle must be overcome. The chipping of keyways in shafting and pulleys is of common occurrence where the work must be done at night or when repairs or additions are to be made where the machinery is already in place. A saving of much time and money is often effected by chipping under such conditions.

742. Pneumatic Hammers. Pneumatic hammers for chip-

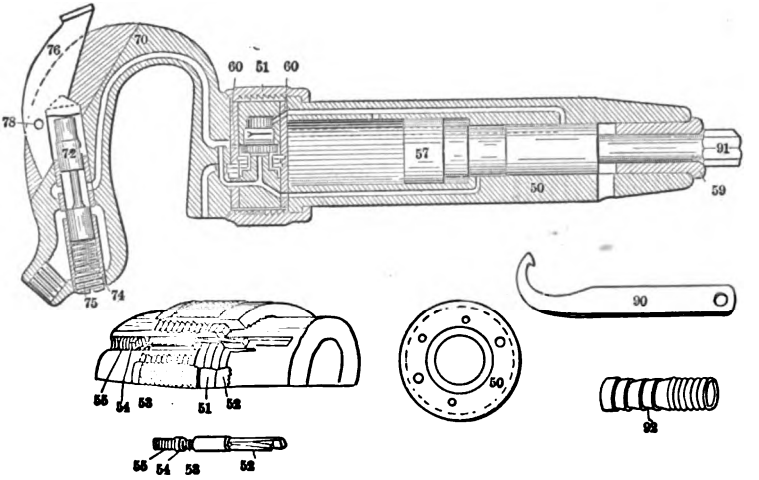

Fig. 742. — Section and Parts of a Boyer Pneumatic Hammer.

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ping and riveting have about superseded the old hand method, especially in shops where compressed air is to be had. A sectional drawing of the Boyer pneumatic hammer together with some of the details is shown in the illustration, Fig. 742.

743. The Chisel. In the cold chisel we meet another modification of the wedge in its application to such familiar tools as the plane, the knife or the chisel. Presenting the edge of an ordinary pocket knife at various angles to a lead pencil will produce all the characteristic chips of the drawknife, the wood chisel, the plane and the cold chisel.

For ordinary work the angle between the cutting faces of cold chisels and cape chisels should be about 60° and the edge ground slightly convex. Harden the cutting end of the chisel by a sudden quenching in brine after it has been heated to a low, cherry-red. Brighten both faces and draw the temper to a straw or brown color. On account of the varying quality of steel, and the various methods of hardening, the best temper can be obtained only by trial. An edge too brittle, one that crumbles or splits, should be re-ground and the temper drawn to a darker color. An edge too soft, one that turns over or upsets, must be re-ground, re-hardened and the temper drawn to a lighter color. Use plenty of water when grinding tools and do not bear too hard on the stone; overheating may thus be avoided. Overheating is indicated by a change in color, and should this occur it will be necessary to re-temper the tool.

744. The Work. When possible, place the work to be chipped on a flat surface and mark off all horizontal lines with a surface gage. Rough surfaces should first be chalked so that the scriber may produce well-defined lines. A solution of copper sulphate, applied with a brush to a clean iron surface, will deposit a thin coat of metallic copper on which any lines that may be drawn are readily seen. After drawing the horizontal lines, vertical lines may be drawn with the scriber guided by the try-square blade, the beam of which rests on the flat surface. Measure all lines thus drawn to make sure that no error exists.

745. The Cut. In clamping work in the vise, copper jaws should be used to protect the finished surfaces. In commencing the cut the chisel is grasped in the left hand with the thumb and index finger close up to the head. In order to lessen the liability to injury, the thumb and index finger should be relaxed,

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the second and third fingers should grip the chisel tightly, while the little finger is free to guide the chisel as desired. In grasping the hammer the little and index fingers should be rather slack, while as before the second and third fingers grasp firmly; it will be found that a hammer so held may be swung more steadily and with greater freedom than when held otherwise. In starting the cut care should be taken to hold the chisel at such an angle that when the blow is struck the cutting edge will not glance below the line and ruin the piece. Hold the cutting edge firmly against the work, at the proper angle, and strike light rapid blows until the cut is fairly started, when a slow heavy stroke will prove the more effective. On account of the brittleness of cast iron it is necessary to commence cuts from each end which meet at some intermediate point, thus avoiding the danger of breaking off the corners. The object striven for is a smooth, even surface; from time to time this should be tested with a straight-edge in various positions to locate the high places. In chipping wrought iron or steel it will be found advantageous to coat the cutting edge of the chisel with oil. For a finishing cut, which should be light, the chisel may be ground more acutely and the edge whetted on a slip stone.

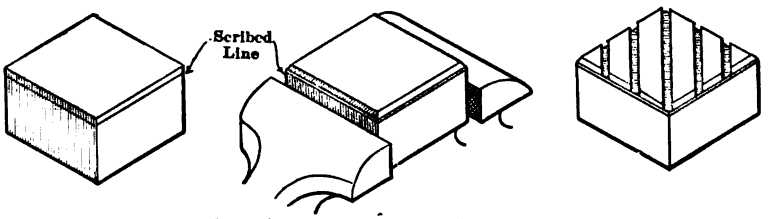

FIG. 745. — Method of Chipping.

The method of chipping a surface over 2 inches wide is shown in figure 745. The piece, if possible, is clamped in the vise with the scribed lines projecting above the jaws. A chamfer is cut along the edges with the flat chisel down nearly to the line, and may be straightened with a bastard file. With the cape chisel diagonal grooves are now run across the surface as indicated, their truth being tested with a straight-edge. Care must be taken not to cut below the general surface. The strips of remaining metal, which are about the width of the flat chisel, may be removed with it; these cuts while still requiring care are guided

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by the fairly accurate grooves and may be heavier in proportion. The constant trying of the chipped portion as the work progresses is the only way to insure accuracy.

746. Chipping Grooves. In working out grooves or keyways with a cape chisel care should be taken to keep as close to the lines as possible, a light cut being made from end to end. This cut will serve as a guide for the others, which may be any desired depth. In working out a wide groove a cut should be taken on each side close to the lines; the stock between these channels may then be removed with heavy cuts.

Filing and Files

751. Application and Practice. In fitting and finishing machine parts it is often necessary to eliminate the furrows and ridges which compose the surface left by the chisel, planer and shaper; filing is then resorted to. Files are also used whenever a minute reduction in size is desired, for by their careful and skilful use great accuracy may be obtained. In order to render a rough surface smooth, files of varying degrees of fineness are used; the coarse file is followed by the finer one and the work finished in turn by the finest.

752. The Tools. A file is a piece of hardened steel of the desired shape and size, the surface of which is cut into by a series of grooves which form sharp points or edges called teeth. These teeth are of uniform height and are so arranged that, while each one cuts a furrow of its own, those that follow serve to level the ridges thus formed, leaving practically a smooth surface. The teeth formed by the grooves act on the surface as a series of small chisels, each removing a small chip.

The only other tools necessary for the filing are the *file card*, which is essentially a wire and a bristle brush on the same handle, used for the purpose of brushing particles from the teeth of the file; a small *copper chisel* for pushing such "pins" from between the teeth as cannot be removed by the use of the card; and a piece of chalk.

753. Care of Files. A dull file cannot be sharpened and in this respect it is unlike other tools; considerable care should therefore be exercised to keep it sharp and in good condition. Files should never be abused by laying them on top of each other or against other tools. When in use the file is liable to "pin," *i.e.*, small particles of stock stick between the teeth and scratch

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the work; especially is this so in the case of wrought iron and steel. To obtain the best results, it is necessary to clean the file at short intervals, not only during its use but before it is put away. The cleaning is effected by the use of the file card or cleaner and in some cases by means of a piece of copper.

754. Cross Filing. In moving a file endwise across the work commonly called cross filing, the point of the file is held between the thumb and the first finger of the left hand, while the handle is held by resting the thumb of the right hand upon it and letting the end stand against the palm of the hand, the fingers gripping it lightly. In moving the file forward over the surface considerable downward pressure must be applied to cause it to "bite." All pressure should be removed in the return stroke and in many cases it will be found advantageous to lift the file entirely clear of the work. In cross-filing there is a tendency for the hands to swing in arcs of circles about the joints of the arms while the body swings more or less, depending on the work. To overcome these tendencies great care should be taken to move the file in a plane parallel to the surface, as any rocking motion will result in a rounding of the edges. Owing to the convexity of a file, comparatively few of its teeth are cutting at any one time; thus it will be seen that short strokes may render the surface of the work concave, while with the long ones it may be either flat or convex. It will be noticed in filing that small grooves are left on the work at each stroke, and that when the strokes are all made in the same direction these grooves become deeper, necessitating their removal by means of a finer grade of file.

755. Diagonal Filing. By changing the angle of the direction of the stroke with the work at short intervals, the grooving mentioned above may be avoided. This enables the file to take a better cut, since the grooves, running at an angle to the cut, cause the file to "bite" more freely and the particles to be more easily separated. This also enables the workman to see just where the file is cutting and to gage the stroke so that the desired part of the surface will be removed. This method is called diagonal filing.

756. Draw Filing. When filing is done by moving the file sidewise across the work it is called draw filing and is very generally used in finishing turned work where it is desired to remove the circular tool marks and to lay them endwise. In draw

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filing the file is grasped with both hands, one at either end, and drawn sidewise toward the operator. Care should be taken to hold the file so that the teeth will cut as it moves away from the work and to relieve the pressure on the return stroke as in cross filing. In draw filing the cut is not as deep as in cross filing, the teeth standing at such an angle to the direction of the motion that a light shearing rather than a cutting effect is produced; very smooth work may be done by this method. A second cut or smooth file is best suited for draw filing.

757. Files and Their Characteristics. A file, as we have learned, is a piece of hardened steel of the desired shape and size, the surface of which is cut into by a series of grooves which form sharp points or edges called teeth.

The *kind* of a file, as will be seen from the table, usually refers to its cross-section and shape, such as flat, mill, hand, square, round, etc.

The *cut* of a file designates the character of its teeth. It is single cut when the teeth are cut in one direction only, double cut when the teeth are cut in two directions, rasp when the teeth are pointed and have no connection with each other.

Coarseness refers to the size of the teeth as designated by the terms coarse, bastard, second cut and smooth; these may refer to any and all of the kinds and cuts mentioned. A *safe edge file* has one of its edges smooth and may be any kind or cut. The flat or hand file, double cut, is commonly used to produce flat surfaces. The mill file, single cut, is used for lathe work. In reference to coarseness, the bastard is best adapted for rough work; the second cut, while not cutting as rapidly, produces a smoother surface; finished surfaces are produced by means of the smooth file.

758. File Table, Shapes, Cuts, Uses, etc.

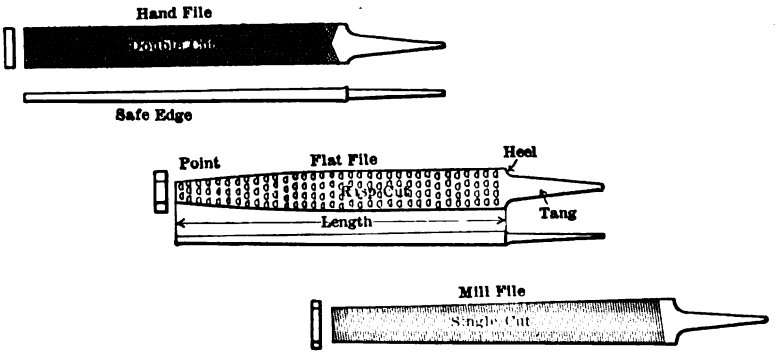

FIG. 758*a*. — File Nomenclature.

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TABLE OF FILES

Kind or Name of File	Section and Shape	Ordinary Cuts	Ordinary Coarseness	Use in Machine Shop
Flat.	Quadrangular. Taper Width. R'ding Lg'thwise. Taper Thickness.	Double Cut.	Bastard and Second Cut.	Quite common; not confined to any specific kind of work, and employed for a great variety of purposes.
Mill.	Quadrangular. Taper Width. Taper Thickness. A Thin File.	Single Cut.	Bastard.	Draw filing, for lathe work, and to some extent for finishing brass and bronze.
Hand.	Quadrangular. Parallel as to Width. Taper Thickness.	Double Cut.	Bastard. Second Cut. Smooth.	For finishing flat surfaces; owing to its shape and its having one safe edge, it is particularly useful where a flat file would not answer.
Square.	Square. Tapers both ways.	Double Cut.	Bastard.	Key-ways, rough work, and principally for enlarging apertures of a rectangular shape.
Round.	Circular. Taper.	Single Cut. Spiral.	Bastard.	For enlarging round holes, and shaping the fillets on internal angles.
Half Round.	Segment. Taper.	Double Cut.	Bastard and Second Cut.	For a variety of uses on account of its shape; quite common.
Three Square.	Triangular. Taper.	Double Cut.	Bastard.	For filing acute internal angles, clearing out square corners, filing up taps, etc.

FIG. 758*b*.

SCRAPING

761. Scraping a Plane Surface. After reading what has been said relative to scrapers in Chapter 4, Section 433, the reader is ready to commence the operation of scraping a surface.

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Placing the piece, previously trued by planing and filing, at a convenient height for the work — it should not be clamped, for clamping is liable to spring the piece — it is brushed to remove any dust or dirt that may be on the surface. Any burrs, fuzz or irregularities are removed by the use of smooth or dead smooth files. The surface plate is now applied; before applying, however, its face is wiped and coated with the marking material. A marking material may consist of any red or black mixture that is not gritty; a mixture of lard oil and Venetian red makes an excellent marking substance. A surface plate is applied face downward on the work and rubbed back and forth over the entire surface; no pressure is necessary as the weight of the plate is sufficient. Upon the removal of the plate irregular patches of marking material will be found, which indicate the high spots on the surface; a few strokes of the scraper will remove them.

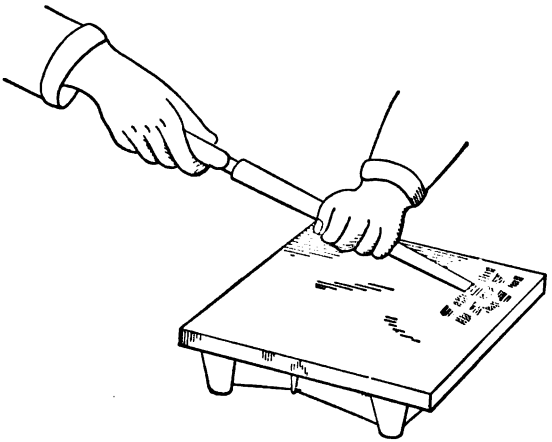

FIG. 761. — Scraping a Surface Plate.

The handle of the scraper is held in the right hand with the thumb extended along the top, as was the case in grasping the file. The blade is grasped with the left hand, as close to the cutting edge as is convenient. The scraper is usually, though not always, held at an angle of 30° with the work, and only that amount of pressure necessary to remove the required metal is applied. The scraping is effected by pushing the scraper away from the operator. The cuts are square and vary from $\frac{1}{8}''$ to $\frac{1}{4}''$

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on a side and are $\frac{1}{8}''$ to $\frac{1}{4}''$ apart. They are taken at right angles to each other in such a manner as to give to the surface a checker-board effect. After the surface is scraped both ways in the manner indicated, the workman should wipe his hands free of grit and rub it over the entire face of the surface to smooth the marking; the plate is then applied to the work as before, and the operation repeated. The truer the surface becomes, the thinner should be the coating of marking material on the plate.

Turpentine is often used advantageously, for, in addition to lubricating the surfaces, it also facilitates the work of scraping.

762. Scraping in the Lathe. Scraping in the lathe is a vastly different process from scraping by hand and is resorted to as a substitute for filing. The shank of a lathe tool clamped in a tool post may be used as an improvised support for the scraper. In work of this character it is necessary to take light cuts, to hold the scraper firmly and to work from the center out. Chattering may sometimes be prevented by placing a piece of leather underneath the tool.

Keys, Keyfitting and Broaching

771. Key Nomenclature. The machinist uses the term *key* to designate that piece of steel, imbedded in the shaft and filling a groove in the hub, that holds the parts in their relative positions.

A *key-seat* is the groove in the shaft while the *key-way* is the groove in the hub. Ordinarily keys and key-ways are made to taper, usually $\frac{1}{8}''$ per foot. A straight key is often termed a *feather*. Woodruff patent keys are made by slitting a disc of cold rolled bar across its diameter and imbedding it in a key-seat, made by sinking into the shaft, to the proper depth, a milling cutter, whose diameter is equal to that of the bar. Some provision is generally made for removing keys; either the key-seat is longer than is necessary so that the key may be driven out, or the larger end of the key is provided with a head; in this latter case the key is removed by the use of a pinch bar or wedge.

772. Keyfitting. Ordinary keys are usually machined a trifle larger than the key-seat and then fitted, by filing, to size. The first step in fitting is to determine whether the sides of the key-seat and key-way have been cut straight; any inaccuracy should be rectified by enlarging just enough to straighten them. The corners of the key are very slightly rounded and both the

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key-seat and key-way are coated with some marking material; the key is then lightly driven into position, when it is withdrawn and filed where a bearing is indicated; this process is repeated until a tight driving fit on all sides is secured. A well-fitted key is bedded firmly against the top and bottom and it is absolutely essential that it have a driving fit on the sides, as it is entirely the side fit that is depended upon to hold the shaft and the hub together. The pressure on the top and bottom of the key should be merely sufficient to draw the opposite side of the bore of the hub firmly to the shaft. There is practically no tendency to break the hub or throw the work out of line by making the key fit tight on the sides if the sides be straight; however, it is a very easy matter to crack a hub or to throw it out of line by overstraining at the top and bottom of the key. In fitting, care must be taken to coat the key with the marking material which also acts as a lubricant; if driven in dry, the key will surely cut.

773. Key-way Cutting. Small key-ways may sometimes be advantageously cut by hand in the lathe in the following manner: A special tool, somewhat similar in shape to a boring tool and ground like a slotting tool at the end, is clamped in the tool post and brought up to the bore to be key-wayed; the tool with the carriage is then traversed back and forth through the hub by hand, taking light, planing chips until the work is finished.

Key-ways and key-seats are made in many ways; they are sometimes chipped and filed; more often, however, the milling machine, planer or shaper is used, while in the larger shops specially designed machines called key-seaters are employed.

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774. Table of Standard Key-seats.

KEYS AND KEY-WAYS TAPER $\frac{1}{8}$" PER FOOT

Diameter Shaft In.	Width In.	Depth In.	Diameter Shaft In.	Width In.	Depth In.	Diameter Shaft In.	Width In.	Depth In.
1	$\frac{1}{4}$	$\frac{3}{32}$	5	$1\frac{1}{8}$	$\frac{3}{8}$	9	$1\frac{3}{4}$	$\frac{9}{16}$
$1\frac{1}{8}$	$\frac{5}{16}$	$\frac{3}{32}$	$5\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{8}$	$9\frac{1}{8}$	$1\frac{3}{4}$	$\frac{9}{16}$
$1\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{32}$	$5\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	$9\frac{1}{4}$	$1\frac{3}{4}$	$\frac{9}{16}$
$1\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{8}$	$5\frac{3}{8}$	$1\frac{1}{4}$	$\frac{7}{16}$	$9\frac{3}{8}$	2	$\frac{5}{8}$
$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{8}$	$5\frac{1}{2}$	$1\frac{1}{4}$	$\frac{7}{16}$	$9\frac{1}{2}$	2	$\frac{5}{8}$
$1\frac{5}{8}$	$\frac{7}{16}$	$\frac{1}{8}$	$5\frac{5}{8}$	$1\frac{1}{4}$	$\frac{7}{16}$	$9\frac{5}{8}$	2	$\frac{5}{8}$
$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{1}{8}$	$5\frac{3}{4}$	$1\frac{1}{4}$	$\frac{7}{16}$	$9\frac{3}{4}$	2	$\frac{5}{8}$
$1\frac{7}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	$5\frac{7}{8}$	$1\frac{1}{4}$	$\frac{7}{16}$	$9\frac{7}{8}$	2	$\frac{5}{8}$
2	$\frac{1}{2}$	$\frac{5}{16}$	6	$1\frac{1}{4}$	$\frac{7}{16}$	10	2	$\frac{5}{8}$
$2\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	$6\frac{1}{8}$	$1\frac{1}{4}$	$\frac{7}{16}$	$10\frac{1}{8}$	2	$\frac{5}{8}$
$2\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{16}$	$6\frac{1}{4}$	$1\frac{1}{4}$	$\frac{7}{16}$	$10\frac{1}{4}$	2	$\frac{5}{8}$
$2\frac{3}{8}$	$\frac{5}{8}$	$\frac{1}{4}$	$6\frac{3}{8}$	$1\frac{1}{2}$	$\frac{1}{2}$	$10\frac{3}{8}$	$2\frac{1}{8}$	$\frac{5}{8}$
$2\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{4}$	$6\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	$10\frac{1}{2}$	$2\frac{1}{8}$	$\frac{5}{8}$
$2\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{4}$	$6\frac{5}{8}$	$1\frac{1}{2}$	$\frac{1}{2}$	$10\frac{5}{8}$	$2\frac{1}{8}$	$\frac{5}{8}$
$2\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$6\frac{3}{4}$	$1\frac{1}{2}$	$\frac{1}{2}$	$10\frac{3}{4}$	$2\frac{1}{8}$	$\frac{5}{8}$
$2\frac{7}{8}$	$\frac{3}{4}$	$\frac{1}{4}$	$6\frac{7}{8}$	$1\frac{1}{2}$	$\frac{1}{2}$	$10\frac{7}{8}$	$2\frac{1}{8}$	$\frac{5}{8}$
3	$\frac{3}{4}$	$\frac{1}{4}$	7	$1\frac{1}{2}$	$\frac{1}{2}$	11	$2\frac{1}{8}$	$\frac{5}{8}$
$3\frac{1}{8}$	$\frac{3}{4}$	$\frac{1}{4}$	$7\frac{1}{8}$	$1\frac{1}{2}$	$\frac{1}{2}$	$11\frac{1}{8}$	$2\frac{1}{8}$	$\frac{5}{8}$
$3\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	$7\frac{1}{4}$	$1\frac{1}{2}$	$\frac{1}{2}$	$11\frac{1}{4}$	$2\frac{1}{8}$	$\frac{5}{8}$
$3\frac{3}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$7\frac{3}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$11\frac{3}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$
$3\frac{1}{2}$	$\frac{7}{8}$	$\frac{5}{16}$	$7\frac{1}{2}$	$1\frac{5}{8}$	$\frac{1}{2}$	$11\frac{1}{2}$	$2\frac{1}{4}$	$\frac{3}{4}$
$3\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$7\frac{5}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$11\frac{5}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$
$3\frac{3}{4}$	$\frac{7}{8}$	$\frac{5}{16}$	$7\frac{3}{4}$	$1\frac{5}{8}$	$\frac{1}{2}$	$11\frac{3}{4}$	$2\frac{1}{4}$	$\frac{3}{4}$
$3\frac{7}{8}$	1	$\frac{5}{16}$	$7\frac{7}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$11\frac{7}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$
4	1	$\frac{5}{16}$	8	$1\frac{5}{8}$	$\frac{1}{2}$	12	$2\frac{1}{4}$	$\frac{3}{4}$
$4\frac{1}{8}$	1	$\frac{5}{16}$	$8\frac{1}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$12\frac{1}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$
$4\frac{1}{4}$	1	$\frac{5}{16}$	$8\frac{1}{4}$	$1\frac{5}{8}$	$\frac{1}{2}$	$12\frac{1}{4}$	$2\frac{1}{4}$	$\frac{3}{4}$
$4\frac{3}{8}$	1	$\frac{5}{16}$	$8\frac{3}{8}$	$1\frac{3}{4}$	$\frac{9}{16}$	$12\frac{3}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$
$4\frac{1}{2}$	1	$\frac{5}{16}$	$8\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$12\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{4}$
$4\frac{5}{8}$	$1\frac{1}{8}$	$\frac{3}{8}$	$8\frac{1}{8}$	$1\frac{3}{4}$	$\frac{9}{16}$	$12\frac{5}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$
$4\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	$8\frac{3}{4}$	$1\frac{3}{4}$	$\frac{9}{16}$	$12\frac{3}{4}$	$2\frac{1}{2}$	$\frac{3}{4}$
$4\frac{7}{8}$	$1\frac{1}{8}$	$\frac{3}{8}$	$8\frac{7}{8}$	$1\frac{3}{4}$	$\frac{9}{16}$	$12\frac{7}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$

FIG. 774.

775. Broaching or Drifting. Broaching or drifting may be defined as the process of forming holes in metal by driving or forcing a cutter of the desired form through previously drilled holes. In broaching, the greater amount of stock is always

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removed by drills, if need be, of varying sizes. The square hole in socket or chuck-screw wrenches is generally made with a broach. Key-ways are often cut by the following process of broaching: A broach, whose width is that of the key-way, having a cutting edge and guide lip as shown in the illustration, Fig. 775,

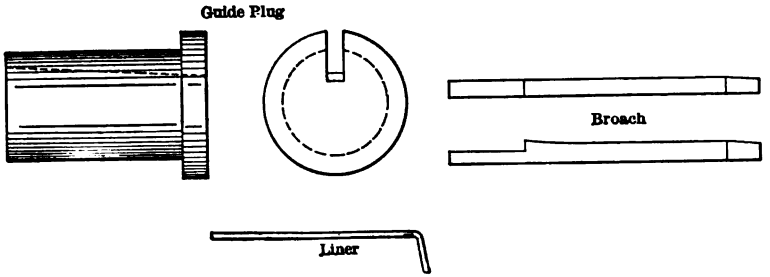

FIG. 775. — Tools for Broaching Key-ways.

is made; a guide plug is then turned to fit the bore of the hub, and a tapering groove of proper depth cut in it; the drift or broach is then driven through the guide groove while its cutting edge removes a chip. In order to obtain the desired depth, liners or shims, cut from sheet metal, are placed in the bottom of the guide groove until a sufficient number of cuts, to secure the proper depth, are made.

FITS AND FITTING

781. Investigation. For an exhaustive investigation of fits and fitting, the student is referred to a paper by the author, and its discussion, forming part of Volume 24 of the Transactions of the American Society of Mechanical Engineers. What follows is in a measure an abstract of the author's paper; however, the formulas relative to forcing and running fits and to limits for limit gages, have been changed in the direction indicated by the bulk of the criticisms. All the formulas will now be found to indicate, in the main, the best practice in this direction.

782. Fitting Processes. Before the advent of modern methods of manufacture, the majority of the fitting was done by hand and was dependent, for its accuracy, upon the skill and judgment of the workman. An experienced workman with a well-educated eye and sense of touch was able to make fits within a limit of a

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few thousandths of an inch, by the old cut and try method. These methods have been superseded and the use of limit gages renders such skill and experience unnecessary. The operation of fitting a plug to a bore was accomplished by a delicate calipering of the bore with inside calipers, transferring this dimension to outside calipers and turning or filing the piece to this dimension. Such uncertain methods as interposing between the legs of the calipers a film of saliva or paper, to secure the fit allowance, were used. The limit thus secured was dependent entirely upon the skill of the workman with the calipers and his judgment regarding the allowance for the fit in hand. Such methods have been superseded and with them the uncertainty and expense of the cut-and-try methods. These, together with much of the skill, have given place to the more rational and cheaper operations of fitting and interchangeability which sprang into use with the advent of limit gages.

When the fit is to be made by hand and the work to be filed to fit a certain gage, or when a certain accuracy is desired, it is the practice, empirically speaking, to leave small lathe work, after the finishing cut, about .002″ large and to remove this stock with what is termed a "float," usually a single cut, bastard or second cut, mill file. The end next the dead center should be filed first so that the gage will just enter, and the operation of finishing gradually carried toward the live center, leaving the surface such that when the gage or caliper is passed over it, no perceptible looseness is detected.

Grinding, scraping, milling and filing may be termed fitting operations, and for more explicit information regarding these subjects the reader is referred to the chapters dealing especially with them.

783. Forcing Fits. Forcing fits may be defined as those machinery fits which require the use of some form of press, generally hydrostatic, to complete the assembling operation. This sort of fit finds its most general application in the fitting of car wheels and axles, in the assembling of cranks and crank pins, cranks and crank shafts and crank shafts and armatures.

Regarding the assembling process, or the manipulation of forcing fits, we find the following governing conditions: (1) The allowance. This should never be so great as to prevent the stress from coming well within the elastic limit or crushing strength

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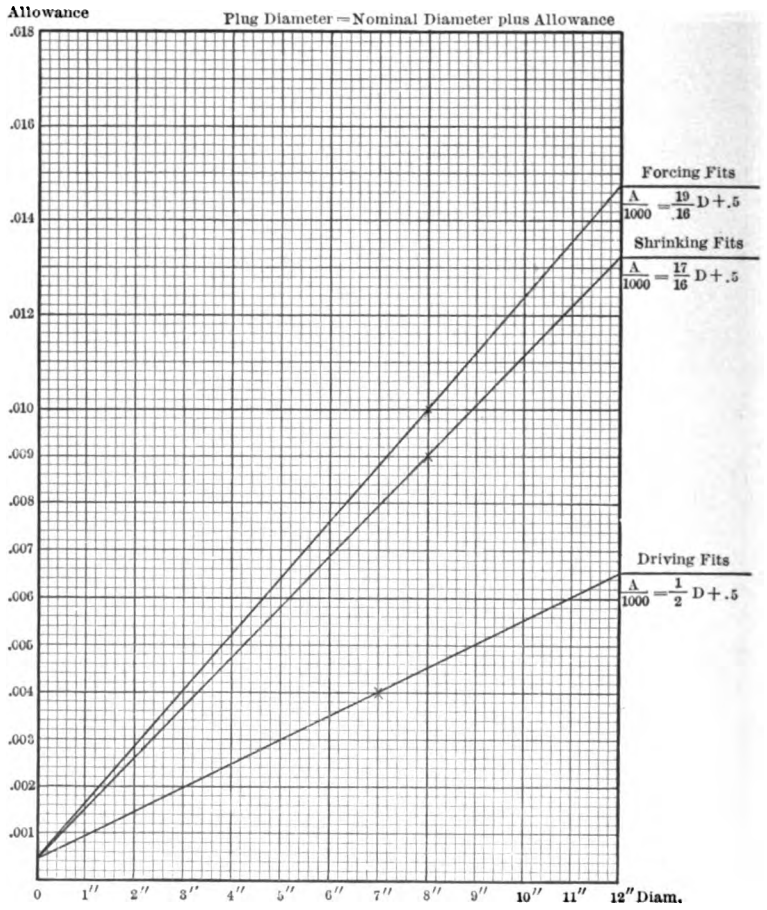
of the materials employed. (2) The surfaces. In general we may say regarding the surfaces for this kind of fitting, that the best results are obtained when both surfaces are ground to fit gages. The conditions, in some instances, render this impracti-



Note: Curves for the Running Fits will be found on the Limits Diagram

FIGS. 783, 785, 786. — Assembling Fit Curves.

cable; however, the surfaces of the pieces to be assembled should be as smooth as it is practical to make them. (3) The lubrication. Linseed oil makes an excellent lubricant for assembling forcing fits. (4) The alignment. It is important to start the

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plug accurately; so important is this that, to secure an accurate alignment, some engineers resort to the use of two diameters — each half the length of the fit — differing by but a few thousandths of an inch. The additional advantage of having to force the plug through but half the length of the fit, it is claimed, greatly reduces the maximum forcing fit pressure.

The following formula gives the allowance for forcing fits in thousandths of an inch:

$A = \frac{1}{8} D + .5$. where A = allowance or difference in diameter between the plug and bore; and D = the nominal diameter of the fit.

784. Forcing Fit Pressures. The following discussion of forcing fit pressures is taken bodily from the author's paper on "Fits and Fitting"; the excuse for the technical nature of the subject-matter and its presentation here being that, on the one hand, the problem of determining forcing fit pressures is by no means simple, while, on the other hand, a knowledge of them is of considerable importance to him who has to do with this class of fits.

In forcing fit pressures the fixed conditions are generally the following: The materials employed; the nominal diameter, the length of the fit, and the thickness of the hub. With these conditions the pressure necessary to assemble a given forcing fit will vary, Mr. Kelley concludes after his experience with about eight hundred forcing fits on regular engine work:

(1) Directly as the area of the surface of the fit for a given diameter.

(2) Directly as the allowance — the difference in diameter between the plug and the bore.

(3) As a function of the radial thickness of the hub.

(4) As the materials employed and the nature of the machined surfaces.

The investigation for a pressure curve was undertaken on this basis — on the assumption that these conclusions are correct. After considerable work a simple equation for a representative pressure curve was established. This equation gave essentially the results obtained by the use of Mr. Kelley's experimentally derived curve, and while possessing the advantage of mathematical deduction, it had the additional advantage of conforming to experience and becomes, therefore, thoroughly practical in its application.

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The curve, (Fig. 784) an hyperbola whose equation is

$$PF = \frac{500}{D^{1.06}}$$

where PF is the pressure factor and D the nominal diameter of the fit, assumes the hub to be twice the diameter of the plug,

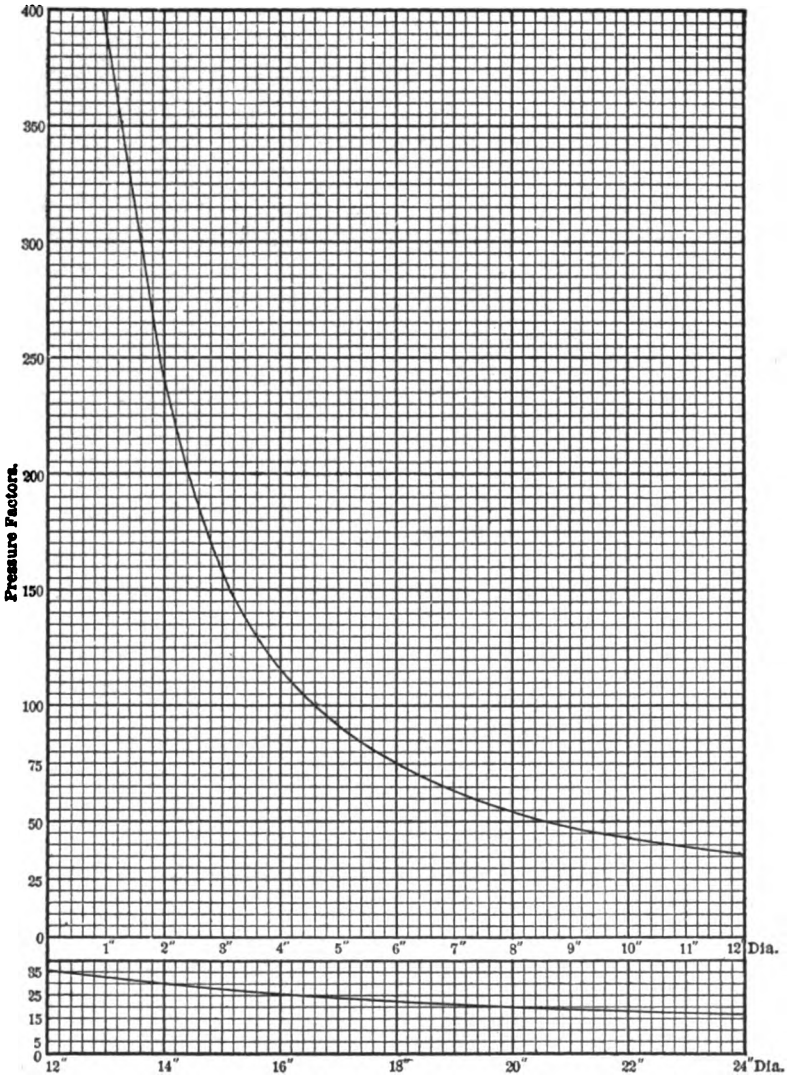

FIG. 784. — Forcing Fits. Pressure Factor Curve.

the materials employed to be machinery steel plugs and cast-iron

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hubs, and the machined surfaces to be practically true and free from tool marks. Should the hub diameter exceed twice that of the plug, the pressure, according to condition three, will be somewhat greater — the amount being obtained by the construction of another hyperbola. Should the materials employed be other than those the curve assumes, the pressure, according to condition four, will again vary, necessitating the determination of another value of *PF*. The few values obtained from the meager data relative to this particular point seem to indicate that a new value of *PF* might be obtained by multiplying *PF* directly by the ratio existing between the average value of the crushing strength of the two new materials and the average value of the crushing strength of cast iron and machinery steel. Moreover, the investigation disclosed the problem to be far too complicated to admit of so simple a solution. The dearth of particular values and the incompleteness of the experiments leading to the above indication were such as to influence the author to say that the statement is of no practical value. However, it may be well to state that the problem was first attacked on the assumption that a solution might be had from a comparison of the moduli of elasticity of the materials. This position was rendered untenable: first, because in materials such as cast iron, which have no well-defined elastic limit, the modulus decreases from a maximum near the beginning of the test; second, as some permanent deformation of the bore and plug generally results as a consequence of the assembling, the elastic limit of the material is obviously passed; this furnished a clew for attacking the problem with reference to the crushing strength. Then again the investigation proceeded with a treatment of the hub as a thick hollow cylinder under tension. Were this assumption correct, the formulas of Professors Barlow and Merriman should be applicable and the tension on every concentric layer, caused by the internal pressure, would vary inversely as the square of its distance from the center. This position is faulty in that cast iron is not homogeneous in texture, is not incompressible, and when used for the materials of cylinders of hydraulic presses, the thickness which obtain are such that the stresses calculated by these formulas would postulate the use of steel to render them reasonably safe. This latter may not be a parallel case, as hydraulic cylinders are usually solid at one end.

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In passing, the author concludes that the influence which the use of different materials will have on the pressure may only be satisfactorily determined by experiment.

The tabulated values of *PF* from this curve will prove the more convenient for ready reference; however, the method of using the curve is as follows: select the nominal diameter of the fit and follow its ordinate up to the curve; from this intersection follow horizontally to the left and read *PF* the pressure factor. The equation for the pressure is

$$\text{Pressure in Tons} = \frac{\text{Area of surface of fit} \times \text{dif. in diam. between plug and bore} \times PF}{2}$$

The result will be the pressure in tons required to force the plug home. A foreman may thus also easily determine whether or not his press is of sufficient capacity for the work in hand.

785. Shrinking Fits. Shrinking fits are employed for a variety of work and are generally used in the smaller shops where no suitable press is to be had for assembling the work.

The allowance for shrinking fits in thousandths of an inch may be obtained from the equation

$$A = \frac{17}{16}D + .5$$

This equation gives allowances which agree with the standard adopted by the American Railway Master Mechanics Association for locomotive wheel-center and tire gages. The agreement is identical to the thousandth decimal place, this being the extent to which their standard is carried. (See Fig. 785, page 178.) The allowances obtained by the use of this formula, while not excessive, are sufficient to insure a tight fit, thus avoiding the danger of excessive shrinkage stresses, ofttimes deemed negligible, which are always additional to those incident to actual service. Taking the modulus of elasticity of steel at 30,000,000 the stress caused by this amount of shrinkage would be about 33,000 pounds per square inch, which is well within the elastic limit of machinery steel.

Considering this class of fitting with a view to obtaining the greatest resistance to tension and torsion, we discover that shrinking fits are far superior to forcing fits, they being, under like conditions, as Professor Wetmore has shown, uniformly about three times as tight both in tension and torsion. Experi-

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ments seem to indicate that, in this class of fits, the resistance to torsion increases more rapidly with the diameter than does the resistance to tension.

In the manipulation, good practice maintains that a piece should rarely be heated hotter than a very dull red heat — about 800° F. — and under no consideration to the scaling point. This temperature, of necessity, limits the fit allowance to something less than 700° x .00000556 = .003892 per unit diameter for cast iron. It will be found, upon an examination of the formula, that the heating to this temperature is ample for the allowances given.

Regarding the process, better results will be obtained if the entire piece be heated slowly and uniformly instead of trying to hasten matters by "blazing up" through the bore. The latter practice is sometimes negative in its results; in cases, permanently reducing the bore diameter instead of increasing it as desired, the expansion being inward instead of outward. In general, it may be said that this class of fitting requires more skill and experience in its manipulation than does force fitting. Not only in the heating and assembling is this skill and experience necessary, but in the cooling as well.

786. Driving Fits. Regarding driving fits, it may be stated that this method of assembling is about obsolete. However, a field may still exist for such small work as the assembling of the smaller pins and cranks of valve gearing, where the allowance A given in thousandths of an inch, obtained by the formula,

$$A = \tfrac{1}{2} D + .5$$

might be used to advantage when the fit is made in an arbor press or by some kindred method. (See Fig. 786, page 178.) The allowances by this formula might also be used for some classes of tight-keyed fits; however, the practice of driving home a plug by means of blows is too crude to be used except where no other method is available.

As will be inferred, what has been said regarding the conditions and preparation of the work for forcing fits applies equally well to driving fits. It might also be stated that where a driving fit must be used, it is essential, when driving the piece home, to have the surfaces well lubricated and the piece containing the bore firmly supported; a timber, a block of wood, a copper or soft-faced hammer should be used so as not to mar the surface.

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787. Running Fits. A running fit is designed to allow the surfaces in contact to move or revolve freely over each other. The more nearly the surfaces in contact approach perfection, the better will be the fit; however, there should be a sufficient difference in diameter to admit of motion and lubrication. The difference in diameter to be allowed in any given fit depends upon the following conditions: the nature of the machined surfaces, the kind of metals in contact, the length of the fit and its diameter, and the pressure and kind of work. The perfection of the fit, depending largely, as it does, upon the surfaces in contact, renders it imperative that they be smooth and true. When possible, in the smaller sizes, bored holes should always be reamed, as this not only insures a standard size but finishes the hole comparatively smooth and true.

Two formulas are given for running fits; one for close running fits, to be used for ordinary work, slow speeds and light pressures, and the other for free running fits, to be used for highspeeds, heavy pressures, rocker shafts, etc. The formula for the close running fits is $A = {}_{1}^{5}{}_{6} D + 1.0$ where A = allowance in thousandths of an inch. These allowances, while seeming unnecessarily small, are such as give a high standard of running fits. The formula for free running fits is $A = {}_{1}^{7}{}_{6} D + 1.5$. It will be remembered, of course, that in order to obtain the shaft diameter, the allowance should be subtracted from the diameter of the bearing, which is generally finished by a standard reamer. This formula assumes the condition of the surfaces in contact to be similar to that obtained by the use of a reamer, and the allowances will be found to fall within the limits given in Section 788 on limits for limit gages.

In passing, it might be well to give a few cautionary sentences regarding the production of satisfactory running fits. Regarding the truth and accuracy of bored holes, practice indicates that the best results are obtained with a very light cut, a high speed and slow feed. In light chuck work there is a tendency, in tightening the chuck jaws, to distort the piece, and it may be necessary in some instances partially to relieve the pressure for the light finishing cut. The most satisfactory results are obtained, in fitting, where limit gages are used. Where no limit gages are to be had, in many instances it will be found advantageous to finish the bore first, as it is easier to fit the shaft to the hole than

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vice versa. When a fit is made, any tool marks left on either the shaft or the bore wear away rapidly and defeat the purpose of the work. Not only is their helical construction conducive to rapid wear, but perfect lubrication is rendered almost impossible as the grooves tend to lead the oil out of the bearing. It is desirable to have the surfaces in contact ground, as they then approach perfection; where this is not feasible, they should be filed and polished. On good work a very few strokes of the file will suffice to remove the tool marks; little or no filing should be attempted after their removal, as the filing of cylindrical work is at its best a negative process where truth and accuracy are to be sought.

788. Limits for Limit Gages. Limit gages, as we are well aware, are used primarily as time savers; they avoid the waste of time in finishing parts unduly accurate, while still having them accurate enough to meet all the demands of interchangeable manufacture. The selection of the limits of variation for any given class of work requires experience and sound judgment. As it is clearly a matter of time saving, the problem resolves itself into two phases: the accuracy and efficiency of the machine on one hand and the rapidity of production on the other. The largest limit of variation, then, that will produce the desired accuracy and efficiency in the machine is the one to be selected. For this reason the selection of limits proves a hazardous undertaking for any but the one who has to do with the production of the machine; however, the following diagram is submitted as being applicable to machine tool, engine work and similar practice.

In the manufacture of limit gages there are reasons why one of the sets should be made one half the allowable variation larger than the nominal size, while the other set should be made just as much smaller. This, it is believed, is the practice of the best manufacturers, though in some of the data investigated, such was not the case. The formula for the curve on the diagram is $\frac{L}{2} = \frac{1}{8}D + .3$ and gives half the limit variation in thousandths of an inch, plus or minus as desired.

An explanation of the limits diagram is as follows: The distance betewen the lines *A* and *B* on any nominal diameter gives the maximum variation of the reamer or bore; as for instance, on the 2-inch diameter, the maximum variation is .0011 inches. The

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line C is the curve for close running fits ($A = \frac{6}{16}D + 1.0$). It will be seen that when the reamer limits are referred to this curve, the maximum difference in diameter between the hole and the shaft is the distance, on any nominal diameter, between the

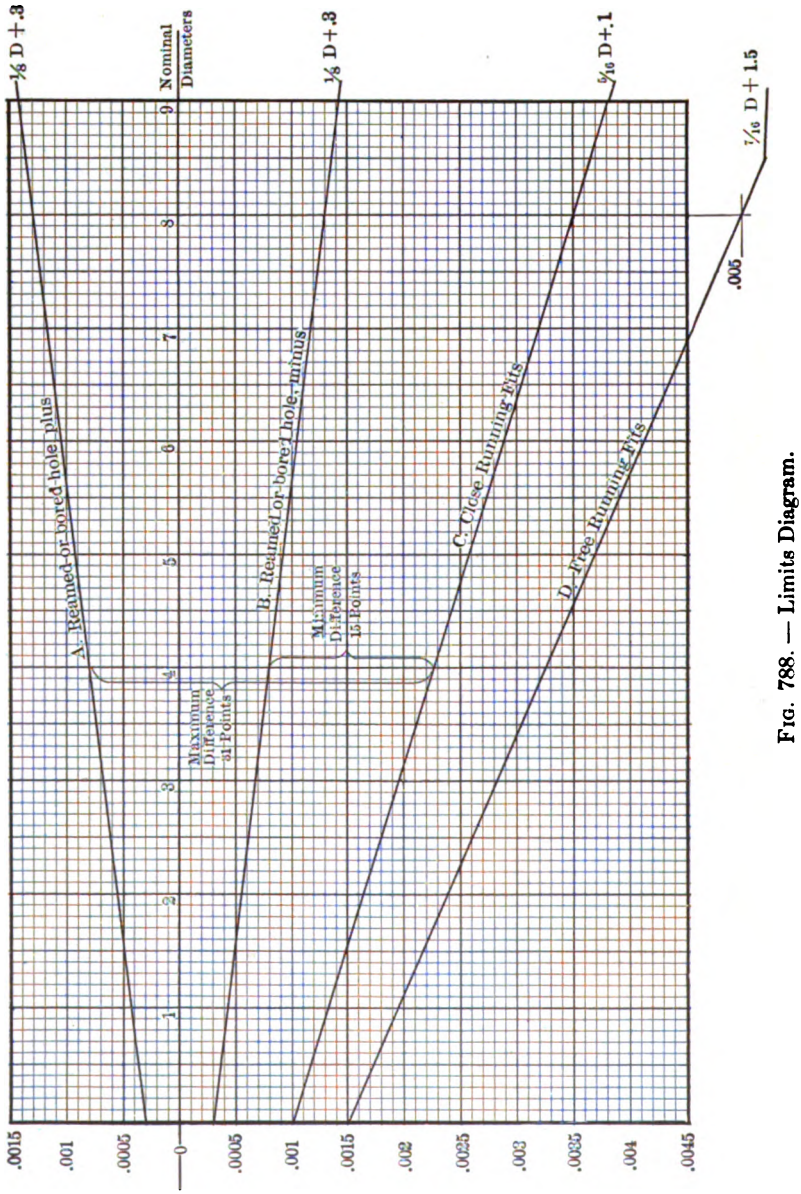

FIG. 788. — Limits Diagram.

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lines A and C; and that the minimum difference is the distance between the lines B and C. For instance, for a 4-inch diameter, it will be seen that the maximum difference is .0031″, while the minimum difference is .0015.″

789. Tabulated Data Relative to Fits and Fitting. In order to place the results of this investigation in the most convenient form, that adequate for ready reference, the allowance values for each class of fits were calculated and tabulated under the following arrangement:

Pressure Factors	Nominal Diam. of Fit	Forcing Fit Allowances	Shrinking Fit Allowances	Driving Fit Allowances	Close Running Fit Allowances	Free Running Fit Allowances	Limits for Limit Gages + or −
	¼″			.0006	.00108	.00161	.00033
	½″			.0008	.00115	.00172	.00036
	¾″			.0009	.00123	.00183	.00039
391	1″	.0017	.0016	.0010	.0013	.00194	.0004
319	1½″	.0023	.0021	.0013	.0015	.0022	.0005
240	2″	.0029	.0026	.0015	.0016	.0024	.0006
156	3″	.0041	.0037	.0020	.0019	.0028	.0007
115	4″	.0053	.0048	.0025	.0023	.0033	.0008
91	5″	.0064	.0058	.0030	.0026	.0037	.0009
75	6″	.0076	.0069	.0035	.0029	.0041	.0011
64	7″	.0088	.0079	.0040	.0032	.0046	.0012
55	8″	.0100	.0090	.0045	.0035	.0050	.0013
48.5	9″	.0112	.0101	.0050	.0038	.0054	.0014
43	10″	.0124	.0111	.0055	.0041	.0059	.0016
39	11″	.0136	.0122	.0060	.0044	.0063	.0017
36	12″	.0148	.0133	.0065	.0048	.0068	.0018
30.4	14″	.0171	.0154	.0075			
26.4	16″	.0195	.0175	.0085			
23.3	18″	.0218	.0196	.0095			
20.8	20″	.0243	.0218				
18.8	22″	.0266	.0239				
17.2	24″	.0290	.0260				
15.1	27″	.0326	.0292				
13.5	30″	.0361	.0324				
	38″		.040				
	44″		.047				
	50″		.053				
	56″		.060				
	62″		.066				
	66″		.070				
$PF = \frac{500}{D^{1.06}}$		$\frac{A}{1000} = \frac{19}{16}D + .5$	$\frac{A}{1000} = \frac{17}{16}D + .5$	$\frac{A}{1000} = \frac{1}{2}D + .5$	$\frac{A}{1000} = \frac{5}{16}D + 1.0$	$\frac{A}{1000} = \frac{7}{16}D + 1.5$	$\frac{1}{2}L + \text{or} - \frac{1}{1000} = \frac{1}{8}D + .3$

FIG. 789.

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CHAPTER VIII

TURNING

Turning Machines

811. Lathes. Lathes are probably used for a greater variety of operations than any other machine tool, and to this reason is due the variety of classes and the wide range of sizes in each class. The typical metal worker's lathe — the most common of all — is the engine lathe; the one to which most of our remarks will be directed.

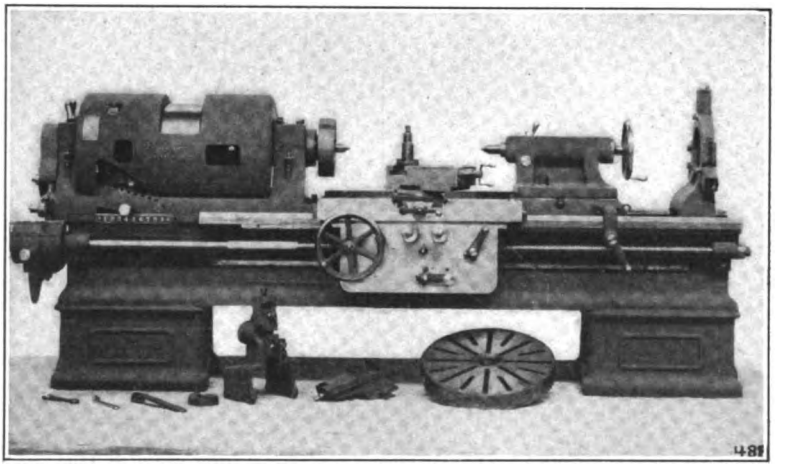

Fig. 811. — Lodge and Shipley Patent Head Lathe.

In cases where the engine lathe could not be used to advantage, special lathes have been designed, among the more common of which are the following:

812. The Tool-maker's Lathe. A tool-maker's lathe is an engine lathe manufactured with great care, and possessing extra attachments that are desirable for tool making.

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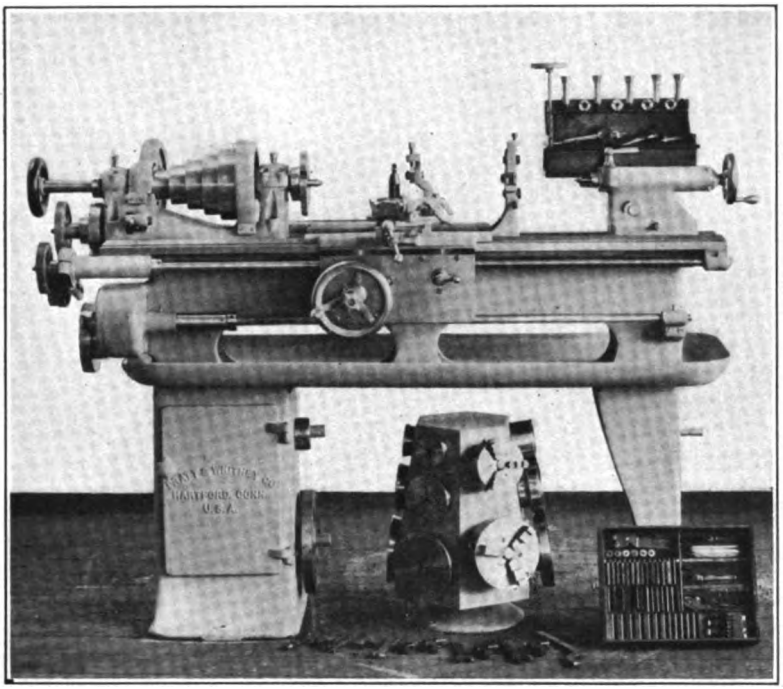

FIG. 812. — Pratt & Whitney Tool-maker's Lathe.

813. The Gap Lathe. A gap lathe is an engine lathe so designed that it will swing pulleys and similar large work through a gap or depression in the bed near the head-stock.

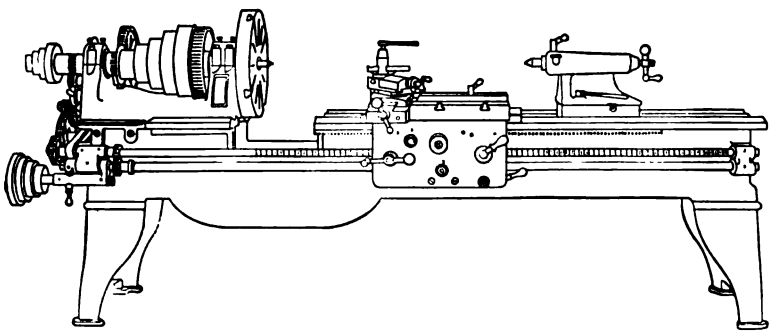

FIG. 813. — Gap Lathe.

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814. The Axle Lathe. An axle lathe is a peculiarly designed lathe with two carriages used for finishing car axles; the work is generally driven from the center.

815. The Wheel Lathe. A wheel lathe is an especially designed lathe for finishing locomotive driving wheels and similar works, the work often being driven from the center.

816. The Turret Lathe. A turret lathe is essentially a manufacturing lathe, the characteristic feature of which is a turret, designed to bring in rapid succession a number of varieties of tools which act on the stock passed through the spindle and held in the chuck. To this class of lathes belong screw machines, monitor and brass-worker's lathes.

817. The Pulley Lathe. A pulley lathe is a type of specially designed lathe for turning pulleys.

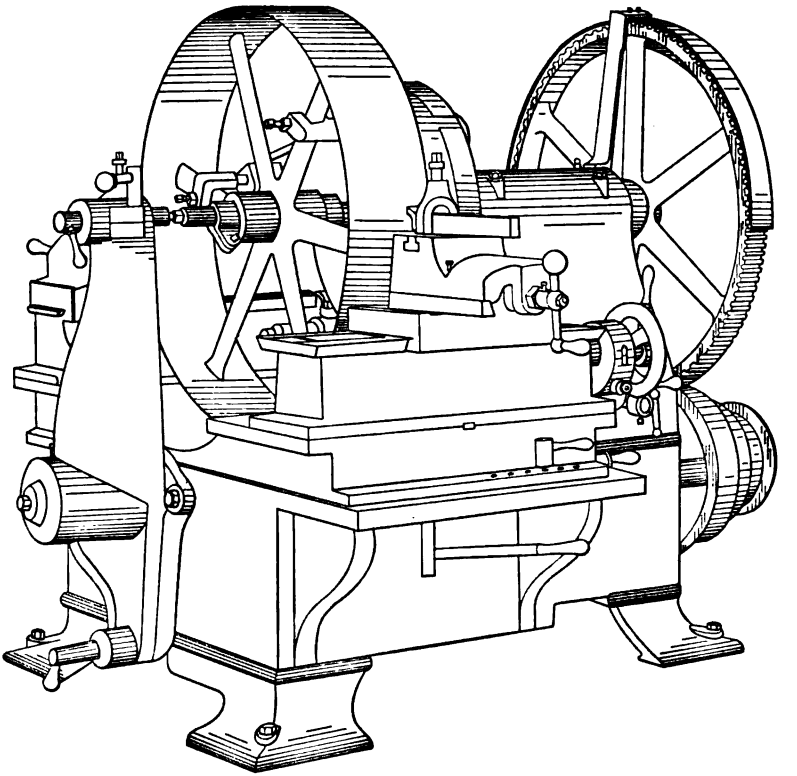

FIG. 817. — Pulley Lathe.

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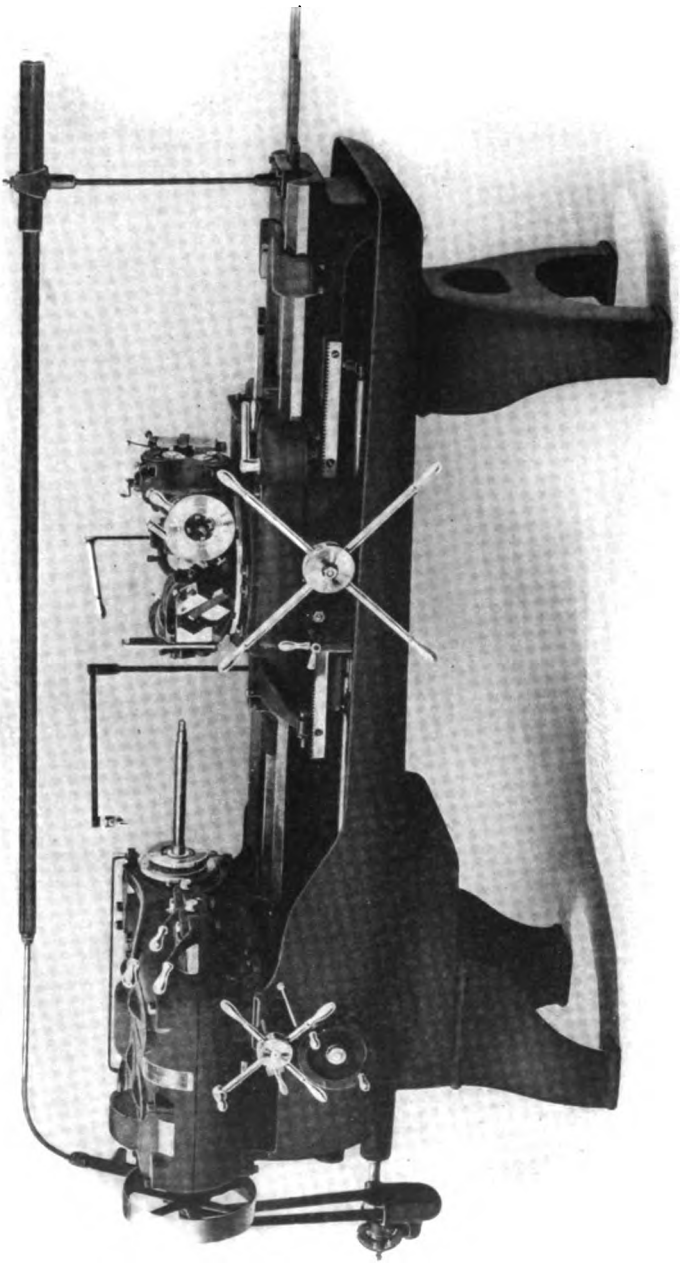

Fig. 816. — Hartness Flat Turret Lathe.

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817½. The Crank-shaft Lathe. A crank-shaft lathe is a type of specially designed lathe for turning multiple-throw crank shafts. The drive is generally uniform from end to end and no difficulty is experienced in keeping any number of crank pins of the same shaft in positive alignment.

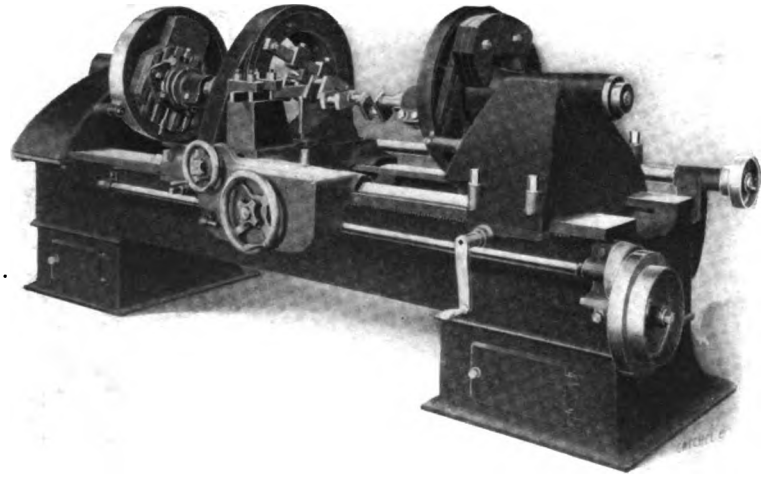

FIG. 817½. — Tindel Albrecht Crank-shaft Machine.

818. The Bench or Precision Lathe. A bench or precision lathe is designed for finishing fine, small work where great accuracy is desired; it resembles closely a watch-maker's lathe and is intended for light work only.

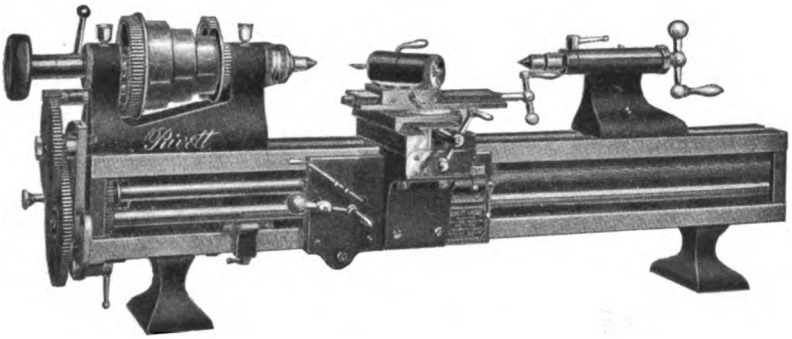

FIG. 818. — Rivet Bench or Precision Lathe.

819. The Speed or Hand Lathe. A speed or hand lathe is similar to a wood-worker's lathe and is designed to rotate the

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work at a higher speed than the ordinary engine lathe; with it such hand tools as gravers and files are used. A great deal of finishing, drilling and countersinking is done with profit on this machine.

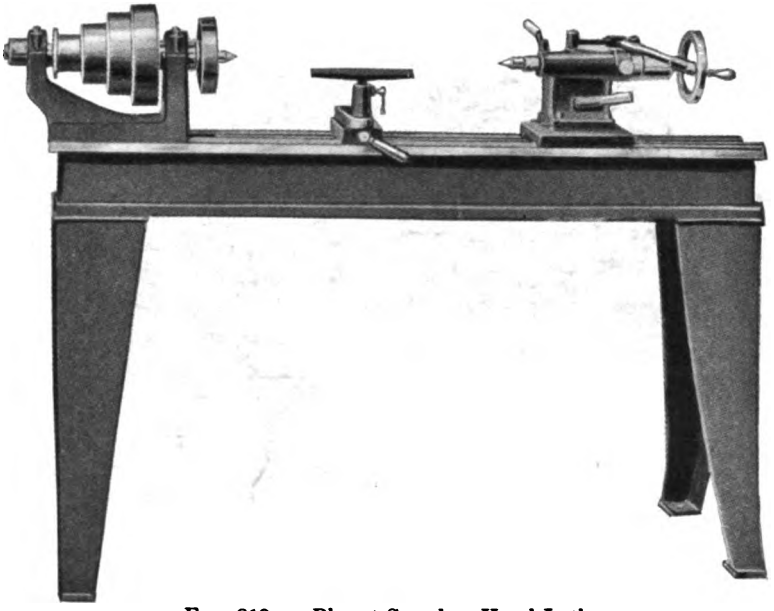

FIG. 819. — Blount Speed or Hand Lathe.

THE ENGINE LATHE

821. Description. An engine lathe is a lathe equipped with a lead screw used for cutting screw threads, and power feeds for actuating the motion of the tool; it is driven from a counter-shaft or by direct connected motor.

In the following description of a standard type of a screw-cutting engine lathe are given briefly the names and functions of its various parts. Referring to figure 821*a*, we have:

B Bed or Shears carrying the working parts of the lathe.
W Ways planed on the bed to guide the carriage and tail-stock.
R Rack for traversing the carriage.
LS Lead Screw used for traversing the carriage.
CGA Change Gear Arm.
FR Feed Rod, which actuates the feed mechanism in the apron.
ASB Automatic Stop Block.
RFC Rod Feed Cone.

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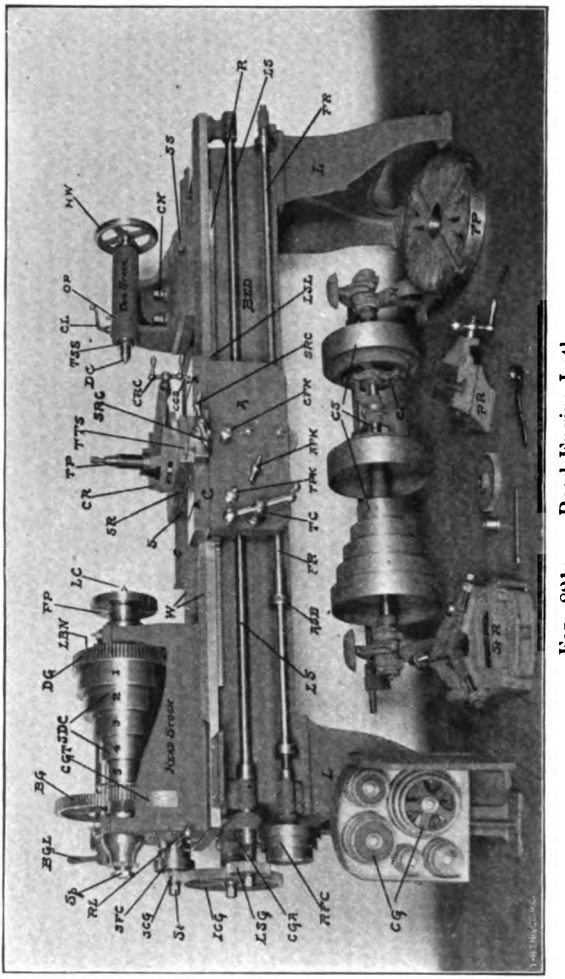

FIG. 821a. — Reed Engine Lathe.

L Legs supporting the bed.
HS Head-Stock carrying driving mechanism.
Sp. Spindle which, through a dog, face-plate or chuck, transmits its motion to the work.
LC Live Center inserted in the spindle.
FP Face-Plate screwed to the spindle.
SDC Stepped Driving Cone, of which 1, 2, 3, 4, 5, are the 1st, 2d, 3d, 4th and 5th steps respectively.

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BG Back Gears used for the slower spindle speeds.

BGL Back Gear Lever for throwing the back gears in or out of action.

DG Driving Gear keyed to the spindle.

LBN Latch Block Nut on the side of *DG*, which fastens the driving gear to the cone pulley when driving direct for the faster speeds, with the back gears out.

RL Reverse Lever.

CGT Change Gear Table.

St. Stud.

SCG Stud Change Gear used in screw cutting.

SFC Stud Feed Cone.

ICG Intermediate Change Gear. (Idler.)

LSG Lead Screw Change Gear.

C Carriage, the upper portion of which (*S*) is called the saddle; the front portion (*A*), rigidly fastened to the saddle, is the apron.

S Saddle, part of the carriage carrying the slide rest and tool.

SR Slide Rest (invented by Henry Maudslay in 1794).

CR Compound Rest.

TP Tool Post in which the lathe tool is held.

TTS Threading Tool Stop, used in screw-cutting, for determining the depth of cut.

SRC Slide Rest Crank, for operating the slide rest.

CRC Compound Rest Crank, for operating the compound rest.

CCS Carriage Clamping Screw.

A Apron, part of the carriage; contains the feed mechanism.

LSL Lead Screw Lever, which clamps the lead screw nut on the lead screw.

CFK Cross Feed Knob, for throwing in the automatic cross feed.

AFK Automatic Traverse Feed Knob, for throwing in the automatic traverse feed from the feed rod.

TPK Traverse Pinion Knob.

TC Traverse Crank, for moving the carriage back and forth on the ways.

TS Tail-Stock.

DC Dead Center; most of the lathe work is swung between the live and dead centers.

TSS Tail-Stock Spindle.

CL Clamp Lever for clamping the tail-stock spindle in position.

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OP Oil Pocket which holds oil for oiling the dead center.
HW Hand Wheel for adjusting the tail-stock spindle and the dead center.
CN Clamping Nuts, for clamping the tail-stock to the bed.
SS Set-over Screws, for setting over the tail-stock spindle when taper turning.
CG Change Gears for screw-cutting and geared feeds.
St.R Steady Rest, used to support long, slender work.
CS Counter Shaft.
Cl. Clutch on counter-shaft.
H Hangers for counter-shaft.
PR Pulley Rest.
FP Face-Plate.

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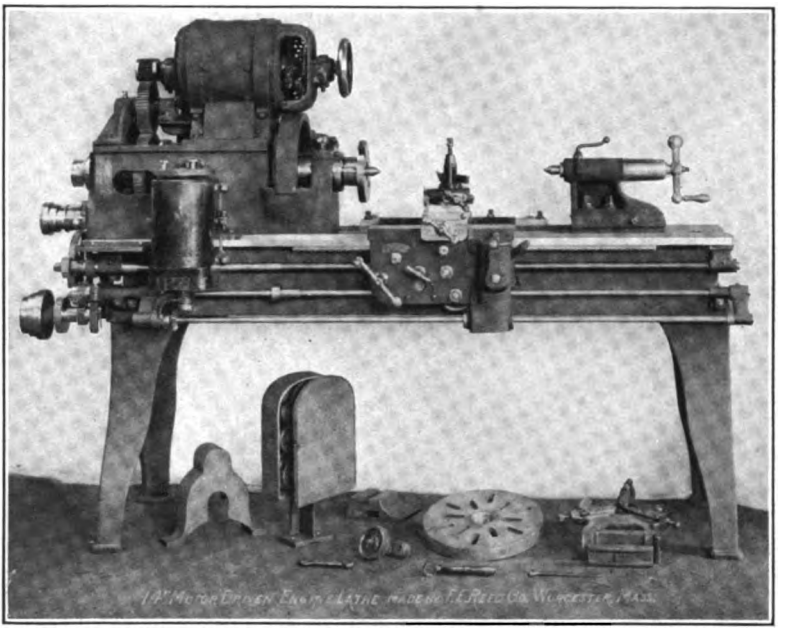

FIG. 821*aa*. — Reed Engine Lathe, Motor Driven.

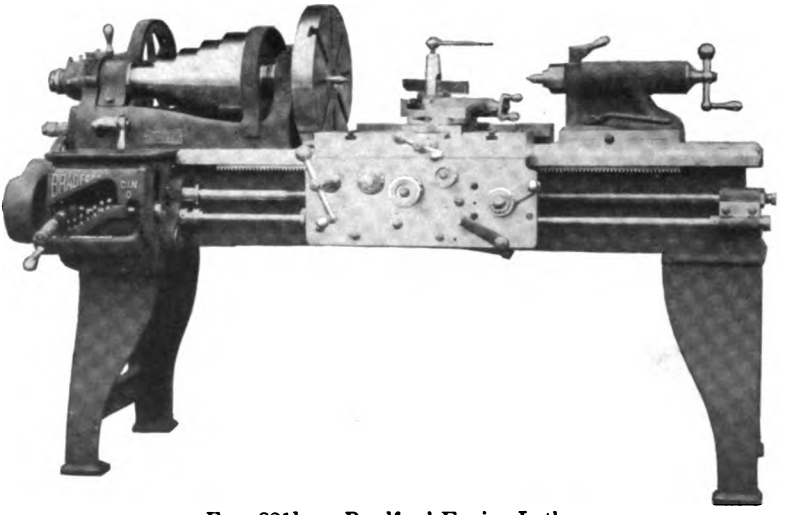

FIG. 821*b*. — Bradford Engine Lathe.

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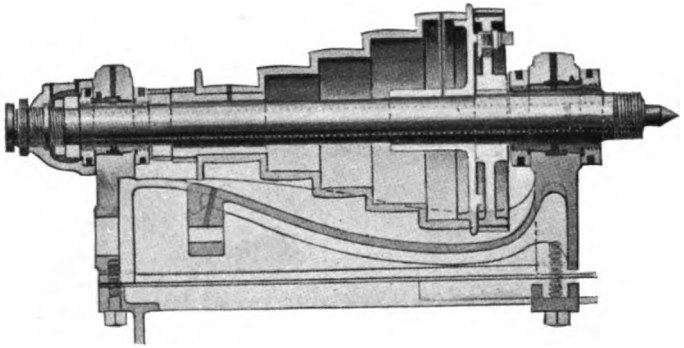

FIG. 821*c*. — Section through Head-stock.

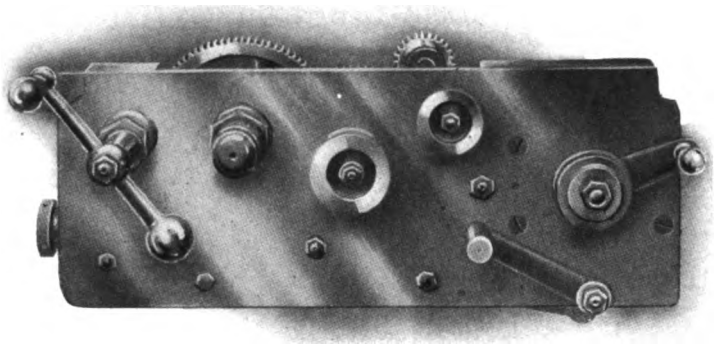

FIG. 821*d*. — Apron Front.

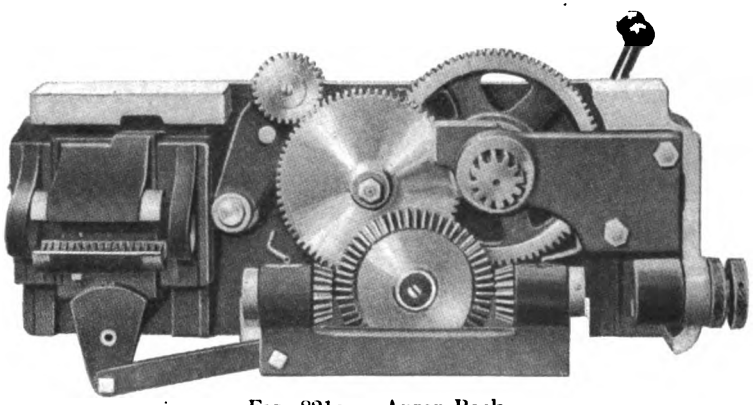

FIG. 821*e*. — Apron Back.

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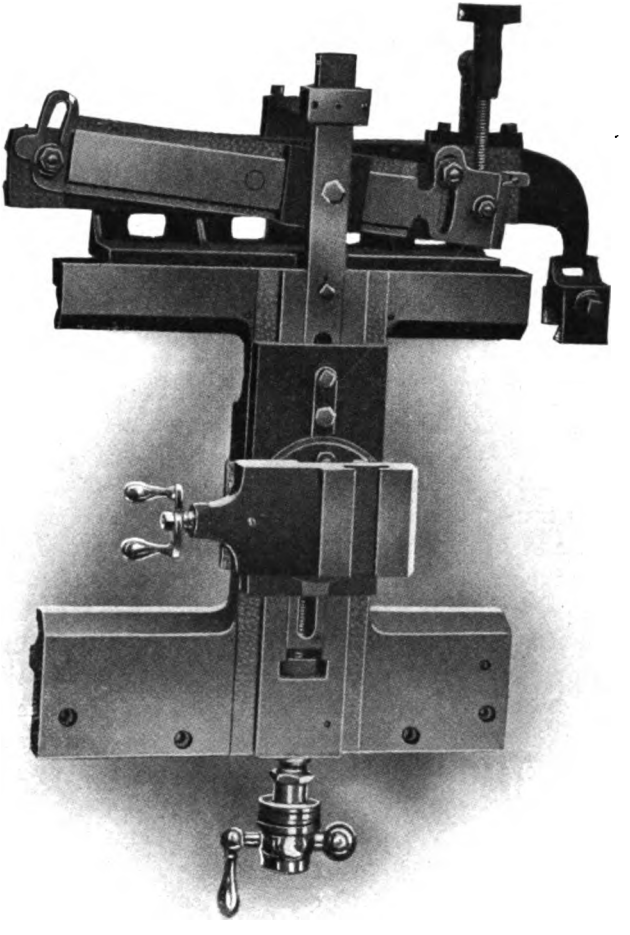

FIG. 821*f*. — Taper-turning Attachment.

822. Characteristic Operations. It is important to understand the following operations and adjustments of the lathe before starting work:

1. The method of obtaining, after its determination, the proper speed for the specific work in hand. This is accomplished by shifting the belt to the proper step of the cone pulley and adjusting the back gears in or out as the work demands.

2. How to instantly reverse the lathe. On most lathes this

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is accomplished by throwing the shipper arm in the opposite direction from that which runs the lathe forward.

3. The method of adjusting the work in the lathe. This topic is treated more fully under the heads of Centering, Sec. 831, Lathe boring operation, Sec. 932, Adjustment in chucks, Sec. 933, Adjustment on face-plate, Sec. 934, and Adjustment on carriage, Sec. 935.

4. The adjustment of the steady and follow rest. The method of adjusting and clamping the steady rest on the ways and the follow rest on the carriage.

5. The various adjustments of the tail-stock, adjusting the tail-stock spindle, clamping the tail-stock in the proper position, how to remove both live and dead centers, and the method of "setting over" for taper turning.

6. The method of adjusting the automatic feed mechanism after the determination of the desired feed. How this feed motion is transmitted by means of feed cones and gears to the feed rod and carriage; the location and operation of the feed knobs and clutches and how to instantly throw either of the feeds into or out of operation. Also the method of reversing the direction of the feed.

7. How the carriage is brought into its proper relation with the work by means of the traversing crank; also the method of disengaging it from the rack by means of the traverse pinion knob, and how to clamp it in position on the ways by means of the carriage clamping screw.

8. The operation of all the other mechanism contained in and on the apron.

9. The adjustment of the slide and compound rest both for straight and taper turning.

10. The correct method of setting the tool and its adjustment in the tool post to obtain the proper angles of rake and clearance for the cutting edge.

11. The method of adjusting the change-gear studs and arm.

Caution. Always stop this or any other machine for the taking of measurements or when it is necessary to leave the machine, be it just for a moment.

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Preparatory Processes

831. Centering. The operations of locating, drilling, and reaming centers on lathe work are of importance and require careful attention. Various methods, depending upon the shape of the piece, are used for locating centers. Cylindrical pieces, or those whose cross-section is symmetrical, are usually centered by one of the following similar methods, already described in Sec. 712 on "Laying out cylindrical work": centering by dividers, centering by surface gage, or centering by hermaphrodite calipers. On the ends of the piece, with a distance somewhat greater or less than half its diameter, four lines or arcs, inclosing a small four-sided figure, are drawn from points on the perimeter. At the center of this figure make the center punch mark, and placing the piece between the lathe centers, revolve by hand to determine the accuracy of the work; an error of $\frac{1}{32}''$ or more is too great and should be corrected. Center punch marks may be crowded over by slanting the punch before striking. Cup centers and center squares are often used for centering where square-ended stock is to be had, and centering machines where great numbers of similar pieces are to be centered.

832. Drilling and Countersinking. Having determined the approximate centers, a small hole should be drilled at each of them. Both ends having been drilled to sufficient depth, the 60° countersink should be used to ream the holes to the proper shape. Care must be taken that the point of the countersink does not touch the bottom of the hole. The combined drill and countersink, with which the hole is drilled and countersunk at one operation, has superseded the method where the separate drill and center reamer are used.

Centers may be drilled in the speed lathes, a drill chuck in the place of the live center being used to hold the drill. The work held against the dead center may then be fed by means of the tail-stock screw or lever. Care must be taken to support the piece, otherwise its weight will have a tendency to throw it out of position. In working wrought iron or steel some lubricant such as lard oil, machine oil or a solution of sodium carbonate (sal soda 1 part, water 20 parts) should always be used; other metals may be worked dry. If the hole is deep the drill should be withdrawn occasionally to clear it of chips and to avoid over-

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heating. Use the highest speed for drilling holes under $\frac{3}{16}''$ in diameter. When a combined drill and countersink is used to countersink work from $\frac{1}{2}''$ to 3″ in diameter, sizes "B" and "F," having body diameters $\frac{3}{10}''$ and $\frac{7}{16}''$ may be used to advantage. The diameter at the base of the cone of the countersink generally varies from $\frac{3}{16}''$ to $\frac{3}{8}''$ in work of the above diameter.

Straight Turning

841. Manipulation. After the operations of centering and countersinking the piece is ready for the lathe. When the piece to be turned is cylindrical there are three distinct operations to be performed, always in the following order:

First. Square up the ends. The roughing cut should leave the stock $\frac{1}{64}''$ longer than the finished length. The right-hand side tool is used and fed outward from the center. For accurate work, re-countersink the centers and finish to the required length, setting the right-hand side tool so that its point leaves no mark on the work. Backing off the dead center a trifle to allow the point of the side tool to just enter the cone of the countersink, and thus to rid it of the burr or wire edge, is oftentimes recommended. The objection cited to this method of getting rid of the burr is that the stock is liable to run a trifle out of center; this latter resulting in the same condition of inaccurate running that exists in a piece which has not had its ends squared.

Second. Take roughing cut over length. Turn the piece to $\frac{1}{64}''$ larger than the finished diameter, using the diamond-point, round-nose, roughing or some similarly ground tool. If, upon calipering at several points, the diameters are found to vary, it indicates that the centers are out of line, and that the dead center must be readjusted. Where several roughing cuts are necessary, they should be as heavy as conditions will permit and be taken over but half the length of the stock. Reverse the piece and turn the other half in the same manner. In this position the first half of the last roughing cut is taken without altering the adjustment of the tool or moving the slide rest; the work is again reversed and the second half of the roughing cut taken.

Third. Take finishing cut over length. With a keenly whetted (stoned) finishing tool or the same tool re-sharpened and adjusted, finish to the exact diameter. As was the case with the roughing cut, the finishing cut is made over but half the

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length; the piece is then reversed in the lathe and the other half finished without altering the adjustment of the tool or slide rest. This minimizes any error in the adjustment of the centers and insures work of a uniform diameter at the ends.

If possible, when the work is to be finished by filing and polishing, a speed lathe should be used. The speed or hand lathe is a lathe similar to the wood-worker's lathe and is designed to rotate the work at a higher speed than the ordinary engine lathe. In addition to being used for filing and polishing, it is often used for drilling and countersinking and such hand turning as employs the use of gravers, files and similar tools.

842. Order of Operations. Always observe the following order of procedure when operating the engine lathe for straight turning:

1. *Adjust the work.* A dog, a device for transmiting the motion from the face-plate to the work, is attached to one end of the piece, a drop of oil is put in the countersink at the other end, and the tail-stock adjusted for holding the piece between the centers. Care should be taken in the adjustment of the centers; they must be immovable in the spindle, perfectly clean, and in line. Both the taper in the spindle and the centers should be wiped clean and dry with new waste before assembling. The hardened center should be in the tail-stock spindle, the soft one in the live spindle; if both centers are known to be hardened, as is often the case, this precaution is unnecessary. The proper adjustment is had when the work is free to turn and held just tight enough to prevent end motion. The operator should see that the tail of the dog does not bind on the bottom of the slot in the face-plate. Carelessness in this respect is a frequent cause of error. As the work becomes heated and expands, it is often necessary to readjust and oil the dead center to avoid turning or twisting off its point. In adjusting the tail-stock on the bed, it should be clamped in such a position that it will not be necessary to run the tail-stock spindle out very far to reach the work, as greater rigidity is secured by keeping the spindle well in the tail-stock.

2. *Adjust the tool and carriage.* Select the right tool and see that it is sharp, *i.e.*, properly ground and whetted. Then adjust and fasten it in the tool post in its proper relation to the work, giving to the cutting edge the proper angles of rake and clearance.

3. *Determine the speed and feed.* Calculate it or consult the

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table, then adjust the belts and gears to obtain this speed and feed.

4. *Pull over by hand.* With all adjustments made, and the tool in its position, pull over by hand to avoid breakage and to ascertain the accuracy of the adjustments.

5. *Start the lathe; depth of cut.* With all clutches released, start the lathe and feed the tool by hand until the desired depth of cut is obtained.

6. *Throw in the feed.* By means of the feed knobs throw in the automatic feed and watch the work carefully to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time. Some lubricant such as lard oil, machine oil, or soda water should be used when turning wrought iron and steel; other metals may be worked dry. The finishing cut should always be very light and made with a keenly stoned tool.

Finishing Processes

851. Filing. Lathe work, that is subsequently to receive a high polish, or to be draw filed, must be filed after the smooth finishing cut. Care must be taken not to scratch the work and to do just the amount of filing necessary to remove the tool marks. Scratching occurs whenever the file "pins" — pinning is the collection of little balls of metal between the teeth of the file. When the file is passed over the surface of the work these particles score or scratch it. See that the file is kept clean, for it is impossible to produce good work unless "pinning" is avoided.

When work is to be filed to fit a certain gage, or when accuracy is desired, it is the practice to leave the work about .002″ large after a smooth finishing cut and to remove this stock with what is termed a "float" file. During this operation of finishing, pinning may be to a great extent avoided by holding the point of the file toward the tail-stock so that it makes an angle with the axis of the work; in this position it should be pushed squarely across the work, that is, at right angles to the axis of the work. During the operation the file appears to be moving toward the left; this, however, is not the case. In some cases, filling the teeth of the file with chalk will prevent pinning.

If the work be rotated too rapidly, and especially if it is large, the teeth of the file will be instantly worn away. An average

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cutting speed for files is about 50 feet per minute. On the forward stroke of the file the pressure should be light and uniform; returning, the file may roll on the work. Owing to the variation of pressure, and to the lack of uniformity in the hardness of the metal, it is almost impossible to file a piece perfectly round. The work should make four or five revolutions for each stroke of the file. When filing to a gage, the end next the dead center should be filed first, so that it will just enter; and the operation of finishing gradually carried toward the live center, leaving the surface such that when the gage is passed over it no perceptible looseness is detected.

852. Scraping. For finishing flat surfaces such as flanges, etc., scraping is often resorted to instead of filing. Before commencing this operation, the workman should review what has been said relative to gravers and scrapers in the chapter on "Cutting Tools," Secs. 432 and 433. The shank of a lathe tool, clamped in the tool post, may be used as an improvised support for the scraper. In work of this character it is necessary to take light cuts, to hold the scraper firmly, and to work from the center out. Chattering may sometimes be prevented by placing a piece of leather underneath the tool.

853. Polishing. Polishing is accomplished in the lathe by the use of emery cloth and oil, the coarser grades of cloth first, following with the finer. The emery cloth is usually attached to a stick which, during the operation, is passed over the tool rest and under the work. Considerable pressure may be exerted by pressing down on the outer end of the stick, which should be moved back and forth continually, in order that the lines cut by the particles of emery will be constantly crossing and re-crossing. In polishing, the lathe should always be run at its highest speed. Watch the dead center; the pressure and high speed may cause it to heat and be twisted off. A clasp made of two pieces of wood is often used for polishing shafting.

Taper Turning

861. Methods of Turning Tapers. There are four methods of turning tapers in common use: (1) The dead center is set out of line with the live center; this is the ordinary method. (2) A lathe provided with a special taper attachment is employed; this is a better method. (3) A special taper-turning lathe, in which

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the head-stock and tail-stock may be set at an angle to the line of the tool-feed motion, is employed; this is the best method. (4) The taper may be turned with the aid of the compound rest. The first method is applicable only for outside turning, while the other three may be used for turning and boring.

It is evident that if a conical or taper surface is desired the tool must travel along a line at an angle to the axis of rotation of the work. This is effected in most lathes by moving the dead center to one side or the other by means of set-over screws in the tail-stock. In doing this, the first operation is to loosen the tail-stock and shove it along the ways until the two centers nearly touch. Back off the set-over screw on that side toward which the center is to be moved, place a scale between the centers and turn the other set-over screw until the proper amount of set-over, as indicated by the scale, is obtained. The first set-over screw should then be brought up to a firm bearing, after which the tail-stock is moved back and clamped in the desired position.

The amount the dead center should be moved over to turn a given taper is dependent upon two things: (1) The angle or the amount of the taper, usually given in inches per foot; and (2) the *entire length of the stock* between the centers, *regardless of the length of the tapered portion.*

Taper is almost always expressed by the difference in diameter per unit of length; *i.e.*, the ratio 1 in 16, or $\frac{1}{16}''$ to $1''$, or $\frac{3}{4}''$ to the foot. When the angle of the taper is given in degrees, the tangent of that angle gives the ratio, for example, tang. $3° - 35' = .0626$; approximately .0625 which is $\frac{1}{16}''$ or $\frac{3}{4}''$ per foot.

862. Brown & Sharpe and Morse Tapers. The two standard tapers in common use are the Brown & Sharpe and the Morse. These tapers are designated by numbers, such as Morse taper No. 2, the number of the taper indicating a certain diameter or size. The Brown & Sharpe taper is supposed to be $\frac{1}{2}''$ per foot, while the Morse taper was intended to be $\frac{5}{8}''$ per foot, but unfortunately the first standards were incorrect and, consequently, the taper of the different numbers of the Morse tapers are not the same and no one of them is exactly $\frac{5}{8}''$ per foot as was originally intended.

863. Rule for Set-over. Setting over the center changes the original distance from the surface of the work to the tool. This

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increases or diminishes the diameter of the work at that end by twice the amount the center is set over. The following is a rule for determining the amount of set-over for a given taper: Multiply the length of the work between the centers, in inches, by the taper per inch and divide this product by two.

$\frac{Length\ of\ Work \times Taper}{2}$ = distance dead center is set out of line with live center. The objection to this method of taper-turning is the unequal wear on the lathe and work centers, due to the set-over. The centers no longer fit the countersink, and while at the dead center the work has a rotating motion on the center, on the live center it has a reciprocating motion. This unequal wear is very annoying as it destroys the truth of the centers and consequently that of subsequent work. The only effective way out of such a difficulty is to grind the centers. In all cases, after turning a portion of the taper, the work should be carefully calipered and any error corrected before it is too late.

864. Theoretical Height of Tool. In taper turning the operations, after setting over the tail-stock, are similar to those of straight turning. The tool is ground with scant clearance, and the keenness obtained by more top rake — because the cutting edge must be placed on the center line for the following reasons.

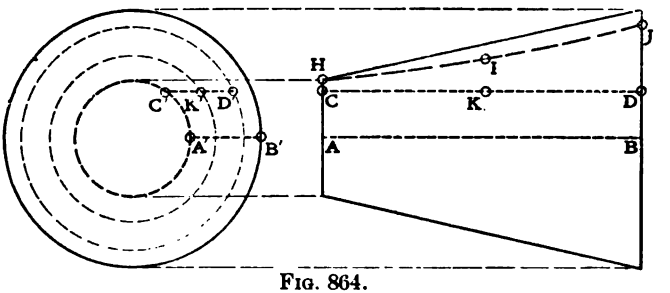

FIG. 864.

Suppose we have turned the piece in the figure (Fig. 864) with the tool properly set on the center. The line AB is the length of the work and consequently the path of the tool. The line $A'B'$ is also the path of the tool and shows exactly the amount the tool recedes from the axis of the work in traveling along AB. It is evident that the travel AB, and the amount $A'B'$ which the tool recedes remain the same whether the tool be set high or low. Setting the tool at the height C and adjusting for the same diameter at

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the small end, we have the path of the tool along CD and the recedence $C'D'$ equal to $A'B'$ as before. A circle drawn through D' represents the diameter the tool is turning when it arrives at D. If we desire to find the diameter the tool is turning at the middle of the line CD, we halve the line $C'D'$ and through the point K' draw a circle which gives the desired diameter; in like manner any number of points may be found and transferred to the front elevation, when it will be found that the line CIJ is curved. A table of tapers per foot and the corresponding angles is given in Sec. 529.

Screw Cutting

871. The Threading Tool. After reading what has been said about the threading tool in Sec. 447, in the chapter on "Cutting Tools," and grinding the tool accordingly, the workman is ready to take up the operation of screw cutting in the lathe. It is evident from the description, that the same tool cannot be used for both right and left-hand threads without changing the clearance. The center gage is used to obtain the correct position of the tool. In adjusting the tool the cutting edges should always be placed on a line with the centers, and so that a center line between them is perpendicular to the surface on which the threads are to be cut. In this position the tool is clamped firmly in the tool post, and care should be taken to see that the dog is tight on the work, and that no end play exists.

872. Change Gearing. The first operation in screw cutting, after grinding and stoning the tool, is the selection of the proper change gears. On most lathes will be found a table of change gears, in the first column of which is given the number of threads to the inch to be cut. In the column marked spindle or stud is given the number of teeth in the gear which belongs on the spindle or stud. In another column will be found the number of teeth in the gear which belongs on the lead screw. With such a table and ordinary pitches, the selection of the proper gears is an easy task. As the intermediate or idler gear is used simply to transmit the motion, any size that will conveniently connect the two is selected. See that no back-lash exists in the gears and also that they do not mesh so close together as to cause unnecessary friction.

When no change gear table is given, or when it is required to cut a thread whose pitch is not given in the table, it is necessary to calculate the change gears. The first thing to do is to determine

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whether or not the gear on the stud makes the same number of revolutions as the spindle. This can be done by counting the teeth of the pinion on the spindle and the teeth of the driving gear on the stud. The speed, in most cases, will be found to be identical and the lathe is geared "even." If for any reason the gears are inaccessible, a trial may have to be made. Put gears of equal size on the stud and lead screw and cut a light thread on any convenient piece. If the thread proves to be the same as that of the lead screw, the lathe is geared "even." If the thread is found to be different, use the thread cut as if it were the real thread of the lead screw, ignoring in your calculations the actual pitch of the lead screw. A rule for obtaining the change gears in simple gearing is as follows:

873. Simple Gearing. — *Rule.* Write the pitch of the lead screw over the pitch of the desired thread in the form of a fraction. The numerator will indicate the number of teeth in the gear to

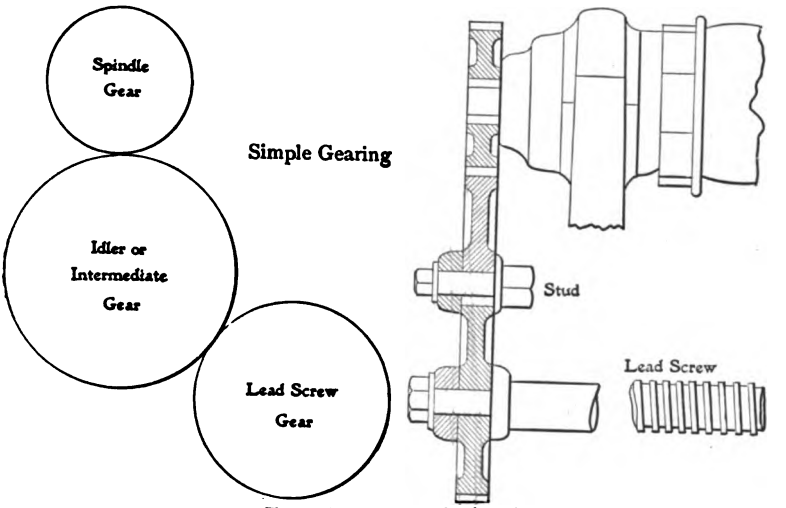

FIG. 873. — Simple Gearing.

be put on the stud or spindle, and the denominator will represent the number of teeth required on the gear to be put on the lead screw; in other words, their ratio. As gears have generally not less than 20 teeth, it will be necessary to multiply both numerator and denominator by some number that will give a combination that can be found among the change gears. For example: the

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lead screw has 7 threads per inch; we desire to cut a standard 1″ pipe thread of $11\frac{1}{2}$ threads per inch; then 7 over $11\frac{1}{2}$ represents the gears to be used. Multiplying by $\frac{4}{4}$, $\frac{6}{6}$, or $\frac{8}{8}$, we have the following combinations from which to select: $\frac{28}{46}$, $\frac{42}{69}$, and $\frac{56}{92}$.

$$\frac{7}{11\frac{1}{2}} \times \frac{4}{4} = \frac{28}{46}, \qquad \frac{7}{11\frac{1}{2}} \times \frac{6}{6} = \frac{42}{69}, \qquad \frac{7}{11\frac{1}{2}} \times \frac{8}{8} = \frac{56}{92}.$$

Since, in a train of gears running together the circumferential velocity of the teeth is the same in all, and since the circumference is proportional to the number of the teeth, we may substitute the number of teeth for the circumferential velocities in the formulas; thus we obtain our proportions.

874. Compound Gearing. When the thread to be cut is of such an uncommon pitch that the method just explained calls for gears one or both of which cannot be found in the assortment

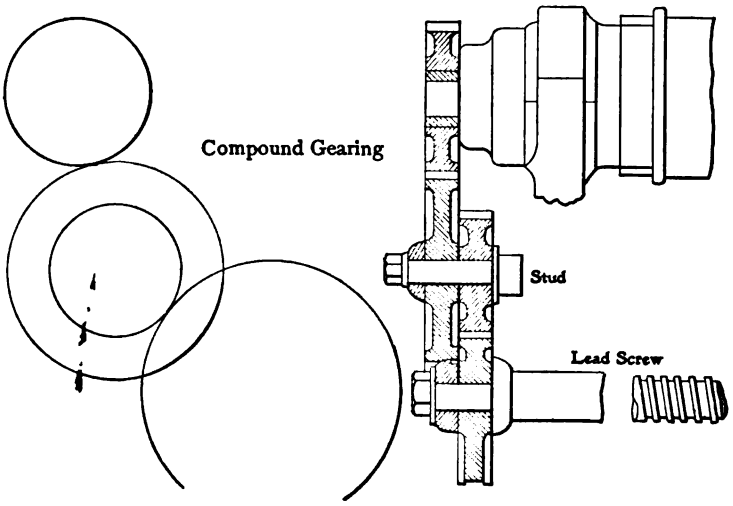

FIG. 874. — Compound Gearing.

accompanying the lathe, compound gearing must be resorted to. In the usual form of compound gearing, two gears of known ratio are placed in the position of the intermediate on its stud. The following is the rule for determining the change gears for compound gearing:

Rule for Compound Gearing. Determine the ratio existing between the gears on the idler stud.

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$$\frac{\text{Mesh with spindle gear; generally outside}}{\text{Mesh with lead screw gear; generally inside}}$$

Divide the pitch of the screw to be cut by this result; substitute this quantity for the "desired thread" and proceed as in the rule for simple gearing.

875. Process and Manipulation. After properly adjusting the change gears throw off the feed belt or feed gear, and bring the tool up to the work, adjusting the threading tool stop and its stop screw so that the tool will barely mark the surface. Release all clutches in the apron; clamp the lead screw nut on the lead screw and *pull over by hand* to determine the correctness of all adjustments. Start the machine and, when the point where the thread is to stop has been reached, withdraw the tool at once, reverse the lathe and allow the tool to travel back to its starting point, at which point the lathe is stopped and the work measured to see if the pitch is correct. Never reverse the lathe until after the tool has been withdrawn free of the cut. Failure to observe this precaution will, on account of the backlash (lost motion) in the gearing and screw, which allows the work to make a part of a rotation before the tool starts back, cause the tool to fail to follow the cut, thus spoiling the work or breaking the point off the tool. The same trouble is likely to occur if the tool is fed into the cut before the work has been allowed to make a few turns in the forward direction.

Too deep a cut has a tendency to break the tool or to bend the work, and to prevent difficulty from this cause is the object of the stop and "stop screw" mentioned in the preceding paragraph. This, "stop-screw" attachment usually consists of some combination of a clamp, screw and knurled nut, by means of which a minute adjustment may be had. When, after measuring, it is desired to take a deeper cut, the stop nut is given a partial turn which permits the tool to be advanced the desired depth of cut. Another attachment which is of assistance in gaging the depth of each cut is the graduated dial, usually found upon the cross-feed screw. The first cut should be the longest, letting each succeeding cut finish a trifle short of the preceding one; that is, the tool is to be withdrawn a little before it has reached the position in which it was previously withdrawn. If this precaution is not observed, the point of the tool is likely to be

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broken off by striking the shoulder at the end of the preceding cuts. The length of the imperfect thread thus produced should never exceed one half a turn. At the end of larger threads a hole is sometimes drilled, or a groove is made around the work with a parting tool, into which the threading tool is allowed to run out; the last half-turn generally being made by hand. As the depth of the thread increases the cuts should become lighter; the finishing cut, made with a sharp, keenly-whetted (stoned) tool, is very light and requires great care; if care is not exercised at this point the thread will be either too tight or too loose in the nut. In a properly fitted thread no looseness is perceptible, and the nut may be turned the entire length of the screw by hand.

When threading wrought iron or steel, the piece should be freely lubricated; lard oil, a weak solution of soap, or a weak solution (1 part soda to 20 parts water) of sodium carbonate (sal soda) may be used.

When necessary to remove the work from the lathe, notice and mark the slot in the face-plate used for the tail of the dog; when replacing, be sure that it occupies its original position.

Never release the lead screw nut, on short work, until after the operation of threading is completed. If it be necessary to remove the tool for re-grinding, readjust it as before to fit the gage; turn the lathe forward — forward on account of backlash — and note the relative position of the cut and the tool point. If the adjustment is incorrect, drop out the idler or intermediate gear and turn the lathe forward until the proper adjustment is obtained; throw in the idler gear and proceed with the cut. In case the thread being cut is a very long one much time will be lost in waiting for the tool to run back. In this case the following method is often used. The lead screw nut is disengaged and the tool moved quickly back to the beginning of the thread; when the number of threads per inch being cut is a multiple of the number of threads on the lead screw, the thread may be caught by engaging the nut at any position, for the reason that when the nut is opened and the carriage moved in either direction, the nut will not mesh again until the carriage has moved a distance equal to the pitch of the lead screw. If the pitch of the lead screw be eight for eight threads, this catches the screw on the next thread; for 16 it misses one and catches the second; for 24 it misses two and catches the third. If the number of threads on a lead screw

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be a multiple of the threads cut, the threads can easily be caught by inspection; for those threads which cannot be caught by inspection the system of marking and stopping, as suggested for cases when the stock is removed, is sometimes used.

876. Order of Operations for Screw Cutting. Observe the following order of procedure when screw cutting in the lathe:

1. *Grind the tool.* The tool should be ground and whetted to suit the thread to be cut; if for a 60° or the standard thread, it should be made to fit the 60° center gage.

2. *Select the change gears.* After determining upon the proper change gears, place them in position, noting that when placed neither backlash nor an undue amount of friction exists.

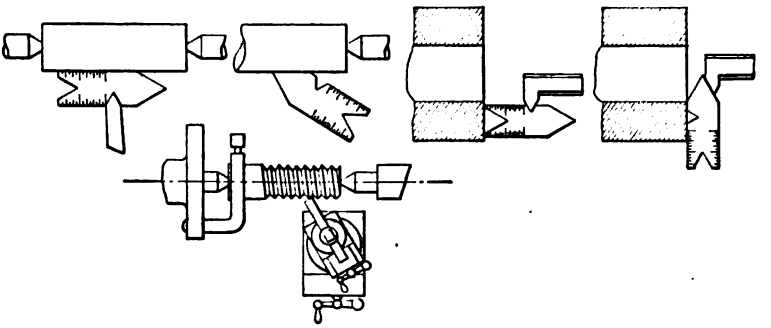

FIG. 876. — Adjusting the Threading Tool.

3. *Throw off the feed belt or feed gear.*

4. *Place the work.* See that the centers are in line, and that the dog is securely fastened to the work. Oil the dead center countersink, see that no end play exists, and put a chalk mark where the thread is to stop.

5. *Adjust the tool.* The cutting edges of the tool should be placed on a line with the centers. Bring the tool into position, using a center gage in adjusting in the manner shown in the drawing.

On lathes which have compound rests the following method of grinding and setting the tool may be used to advantage. As ordinarily shaped and ground threading tools have little or no top rake and for this reason are easily dulled and unsatisfactory; by using a tool forged and ground as shown and setting the compound rest at an angle of 60° with the axis of the work as

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indicated in the figure (Fig. 876), the disadvantages of the other tool are overcome. The tool is given top rake to its cutting edge, which operates on but one side of the thread; the tool is set in the usual manner with the thread gage.

6. *Clutches and lead screw.* With the feed belt off, release all the clutches in the apron and clamp the lead screw nut on the lead screw.

7. *Adjust the stop.* Adjust the stop and stop screw so that the tool will barely mark the work.

8. *Pull over by hand.* Shift the belt to the correct speed — about 15 feet per minute for soft steel or iron — and pull over by hand to determine the accuracy of all adjustments.

9. *Start the lathe.* Start the lathe and take a very light cut to determine the correctness of the pitch.

10. *Proceed with the work.* During the operation the cuts should become lighter as the depth of the thread increases; the finishing cut should be made with a keenly whetted tool and be very light. When the work is removed for trial in the gage or nut, care must be taken to place it in exactly the same position that it occupied before its removal.

877. Notes on Screw Cutting. *Metric screw* threads may be cut on lathes having inch-divided lead screws, by the use of change gears having the proportion 50 to 127, because 127 centimeters = 50 inches (127 x .3937 = 49.9999).

The *lead of a screw* is the distance the thread advances in one turn; in a single-threaded screw the lead and the pitch are the same. In a double-threaded screw the lead equals twice the pitch.

A *double thread* may be cut, when the number of teeth in the spindle gear is even, by dropping out the idler from the spindle gear — having first marked a tooth on the spindle gear and a corresponding tooth space on the idler — and then turning the lathe forward half the number of teeth in the spindle gear. The idler is now replaced and the cutting proceeds as before. A better method is to have slots, diametrically opposite to each other, milled in the face-plate, and to place the tail of the dog in one for the first thread and in the other for the second thread.

A *left-hand thread* is one whose thread inclines so as to be nearer the left hand at the under side, and is cut by inserting a second idler to change the direction of rotation of the lead screw.

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Most lathes are provided with a handle for operating the reversing gears under the spindles and it is only necessary to shift the handle to perform this operation, *i.e.*, reverse the direction of rotation of the lead screw.

Ordinary Thread Proportions

881. The U. S. Standard Thread. The preceding paragraphs under the heading "Change Gears" are written with special

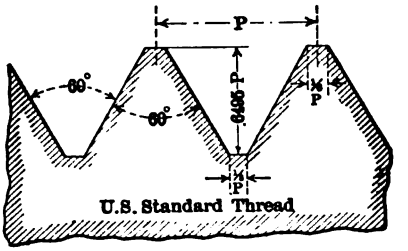

Fig. 881. — U. S. Standard Thread.

reference to the cutting of the U. S. standard threads, though the text is intended to deal primarily with the subject, "Change Gearing" and its application to screw cutting in the lathe. If the student has not already read the foregoing text he is advised to do so for information on this subject. A table of U. S. standard Thread, Bolt and Nut Data is given in Sec. 671, in the chapter on "Screw and Pin Data."

882. The Square Thread. In the square thread the thickness of the thread and its depth are each equal to one half the pitch,

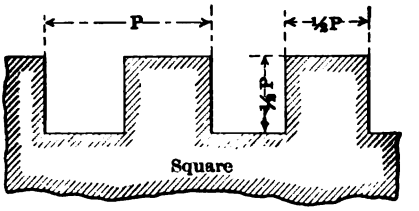

Fig. 882. — Square Thread.

and its sides are parallel. To obtain the diameter at the bottom of a square thread divide one inch by the pitch and subtract it from the outside diameter.

A tool similar in shape to the parting tool is used for cutting

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square threads; its angles of side clearance, however, will vary with every diameter and every pitch of thread. Looking at the end of the common form of tool used for cutting square threads, the cutting portion appears to be twisted to one side, that is, at an angle to the perpendicular axis of the tool. This form of tool must be so shaped as to run smoothly in the thread, and to this fact is due the angularity noticed. The ordinary method of finding the amount of "twist" to give the cutting portion of the tool is as follows: the circumference of the piece to be threaded is laid out on a horizontal line, and at its end is erected a perpendicular whose length is equal to the pitch; a right triangle is then formed by connecting the end of the perpendicular with the end of the horizontal line. The angle between the hypothenuse and the longer leg of this triangle is the angle which the axis of the twisted cutting portion of the tool makes with the perpendicular axis. If another triangle be laid out, taking the circumference at the bottom of the thread, it is easily seen that this angle varies with every cut, and that the method just explained cannot, therefore, be theoretically correct; it is, however, the method usually employed. It is impossible, for mechanical reasons, to cut a perfect square thread with a single tool such as the one described; such a tool will cut a thread whose sides and bottom are curved. To cut a perfect square thread, the roughing cut is made with a single tool, and the sides and bottom finished separately with different tools, each having but one cutting edge and that cutting edge placed on the center. When using the single tool it must be ground like the parting tool, thinner at the bottom than the top to insure clearance.

883. The 60° V Thread. This thread is similar in shape to the U. S. standard with the exception that its side faces meet, both at the top and the bottom, in a sharp edge or corner, giving rise to the name by which it is sometimes known — sharp thread. The side faces of this thread make an angle of 60° with each other, the depth of the thread being the sine of the angle (.866) times the pitch. The diameter at the bottom of the thread, the nominal size of the tap drill, equals the outside diameter of the screw minus the quantity 1.732 divided by the pitch $\left(\frac{1.732}{\text{threads per inch}}\right)$. This thread is chiefly used for small screws, etc., and especially for case-hardened set screws.

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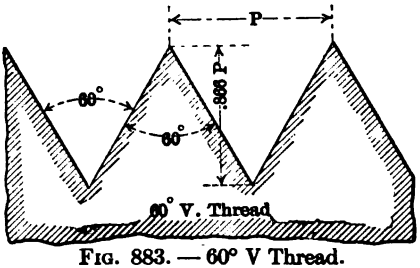

FIG. 883. — 60° V Thread.

884. The Brown & Sharpe 29° Worm Thread. This thread is recommended by Brown & Sharpe for worms and hobs and is the common thread for worm gearing. The sides of this thread make an angle of 29° with each other. The flat at the bottom of

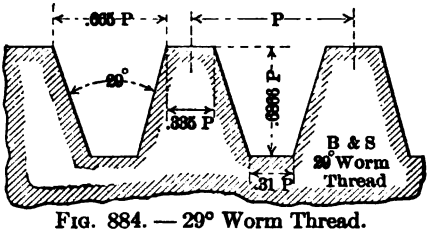

FIG. 884. — 29° Worm Thread.

the thread is .31 of the pitch, while the flat at the top is .335 of the pitch; this, it will be seen, insures a perfect fit on the sides of the thread. The depth of the thread is .6866 of the pitch, and the diameter at the bottom of the thread is obtained by subtracting from the outside diameter the quantity obtained by multiplying twice the depth (.6866 x 2 = 1.3732) by the pitch.

885. The 29° Screw Thread, Acme Standard. On account of

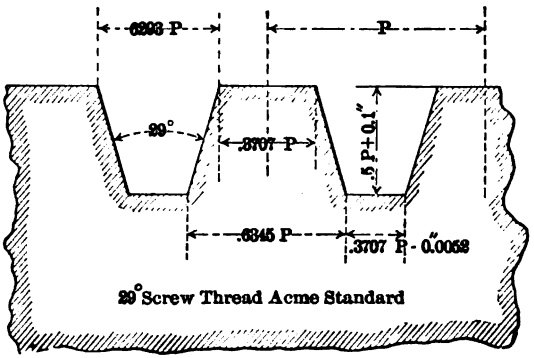

FIG. 885. — 29° Screw Thread, Acme Standard.

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its having but a small amount of side friction, this thread is being used extensively instead of the square thread, where a coarse pitch screw is desired.

The various parts of the 29° Screw Thread, Acme Standard, are obtained as follows:

Width of point of tool for screw or tap thread

$$= \frac{.3707}{\text{No. of thds. per inch}} - .0052.$$

Width of screw or nut thread $= \dfrac{.3707}{\text{No. of thds. per inch}}$.

Diameter of tap = Diameter of screw + .020.

Diameter of tap or screw at root = Diameter of screw

$$- \left(\frac{1}{\text{No. of linear thds. per inch}} + .020\right).$$

$$\text{Depth of thread} = \frac{1}{2 \times \text{No. of thds. per inch}} + .010.$$

886. Table of 298 Screw Thread Parts, Acme Standard.

No. of Thds. per In. Linear	Depth of Thd.	Width at Top of Thd.	Width at Bottom of Thd.	Space at Top of Thd.	Thickness at Root of Thd.
1	.5100	.3707	.3655	.6293	.6345
1½	.3850	.2780	.2728	.4720	.4772
2	.2600	.1853	.1801	.3147	.3199
3	.1767	.1235	.1183	.2098	.2150
4	.1350	.0927	.0875.	.1573	.1625
5	.1100	.0741	.0689	.1259	.1311
6	.0933	.0618	.0566	.1049	.1101
7	.0814	.0529	.0478	.0899	.0951
8	.0725	.0463	.0411	.0787	.0839
9	.0655	.0413	.0361	.0699	.0751
10	.0600	.0371	.0319	.0629	.0681

FIG. 886.

887. The British Standard or Whitworth Thread. The characteristic features of this thread are the rounding off of the thread tops, the filleting in of the roots and the 55° angle which the sides of the thread make with each other. The amount taken off the thread top and added to the root is one sixth of the height

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of a "V" thread whose sides are at an angle of 55° with each other.

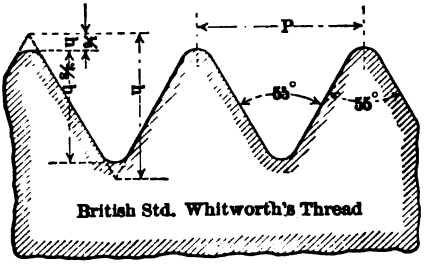

FIG. 887. — British Standard, Whitworth Thread.

888. The Trapezoidal Thread. This thread was designed to embody the advantages of the square and "V" threads, and for use where the pressure on the thread is always in the same relative direction. One side of this thread is perpendicular to the bolt

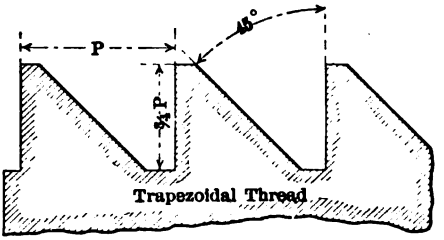

FIG. 888. — The Trapezoidal Thread.

axis, while the other side makes an angle of 45° with it. The amount taken from the top and added to the bottom of this thread is one eighth of the depth of a similar sharp thread; this makes the depth of the thread three fourths of the pitch.

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CHAPTER IX

BORING

Boring Machines

911. Boring Defined. Boring may be defined as the production of internal cylindrical or conical surfaces. Boring machines, like most other machine tools, have their origin in the lathe but, like them, retain but few of its characteristic details. The two classes into which boring machines are divided are the horizontal and the vertical.

912. The Horizontal Boring Machine. The horizontal boring machine, in a common type, retains some of the details of lathe construction in that the head, with its spindle, cone pulley and

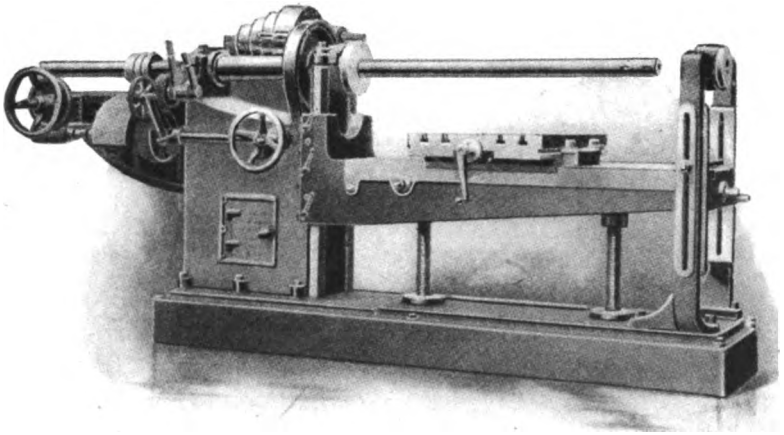

Fig. 912. — Binsee Horizontal Boring Machine.

back gears, resembles that of the lathe. Instead of the bed and carriage, a table for supporting the work, and having vertical, side and longitudinal adjustments, is provided. The end of the

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spindle is provided with an attachment for holding either a boring bar or a drill. The spindle is splined and so designed that, while it rotates with the driving gear, it may be fed through the work, either automatically or by hand; this style may also be used advantageously for many drilling and heavy milling operations.

913. **The Vertical Boring Machine.** Vertical boring machines are commonly termed boring and turning mills; they bear little

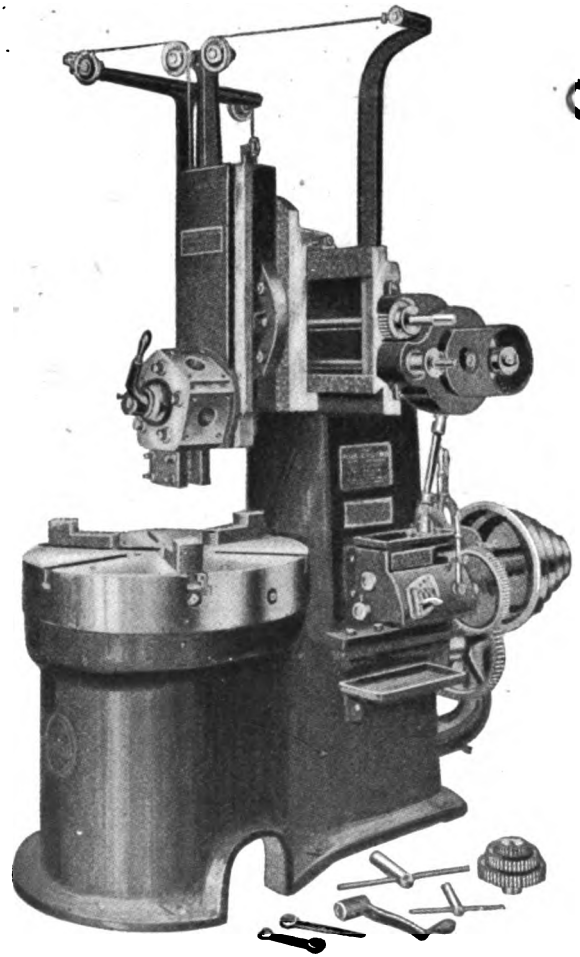

FIG. 913*a*. — Baush 30″ Vertical Boring Machine.

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resemblance to any other machine tool, save possibly to the planer; a common type having the characteristic housings, cross-rail and heads which we are wont to see on planers. In place of the platen this machine is provided with a horizontal circular table which is, in reality, a huge face-plate on which the work is bolted. This table is rotated by means of bevel gears, while the tool, held in

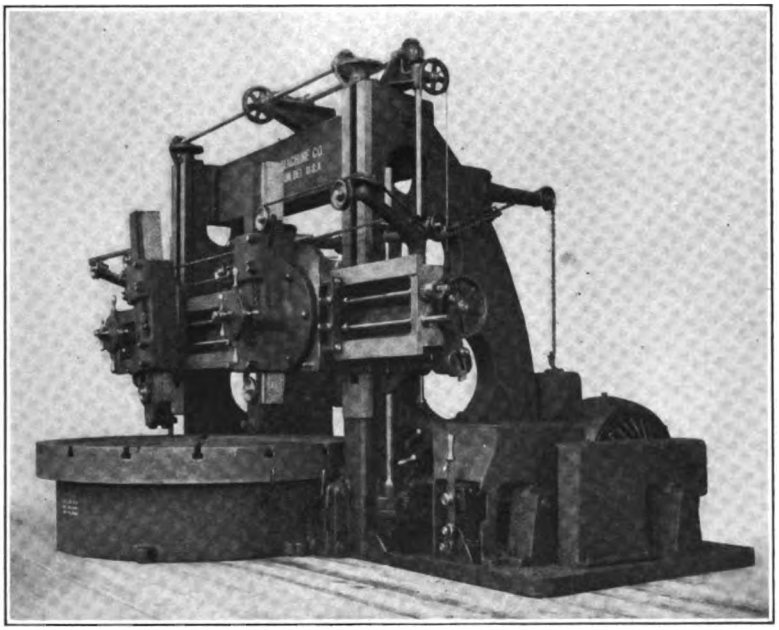

FIG. 913*b*. — Betts Motor-driven Boring and Turning Mill, 7 ft.

an adjustable boring bar in the tool head, operates on the work which is bolted on the table. The saddles, carrying the heads on the cross-rail, may be operated either automatically or by hand, as may also be the bars carried in the heads. These heads may be swiveled at any angle to provide additional adjustment for the tool and to enable taper work to be turned. For face-plate work and such other turning as may be handled, the makers claim to be able to effect a saving of from 40% to 70% when such work is machined on a boring mill.

914. The Lathe as a Boring Machine. The production of internal cylindrical or conical surfaces in the lathe is also termed

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boring. The work is either held in a chuck, bolted on the face-plate, or fastened to the carriage. In this operation the holding or adjustment of the work is of considerable importance and will be divided, for convenience of treatment, into three classes: (1) Adjustment in chucks, or chucking, Sec. 933; (2) Adjustment on the face-plate, Sec. 934; (3) Adjustment on the carriage, Sec. 935.

The Vertical Boring and Turning Mill

921. Function and Limitations. The function of the boring mill is the machining of such cylindrical work as would have to be swung or carried on the face-plate of a lathe. It is essentially a vertical face plate lathe, so designed as to embody the essential characteristics which the lathe possesses for such work, while it avoids such inherent lathe defects as the necessary overhanging parts and the difficulty of adjusting face-plate work.

The advantages accruing from a vertical construction are the facts that the work is easily placed on the horizontal chuck or table; that it is easily centered and fastened there, and that the entire weight of the table and work is taken on a large angular bearing so constructed as to be self-centering, with a tendency to preserve rather than destroy its alignment.

Regarding the limitations, it may be said that for any cylindrical work, which does not require to be swung on centers, the boring mill offers a tool that possesses a few points of excellence over that of the lathe for similar work; and as boring mills are now equipped with positive feeds and screw-cutting mechanism, they not only possess a wide range of usefulness, but for medium and large chuck work have superseded the lathe. The same degree of accuracy which we receive in the lathe we may expect and do receive from the vertical boring and turning mill.

922. Description of Parts. An advanced type of vertical boring and turning machine has the following construction and parts: a rigid *base* or *frame* which supports the table — and in the larger machines the housings — and the entire mechanism; a *table*, in reality a huge face-plate, with its specially designed angular bearing, hollow *spindle* and rotating mechanism; a *cross-rail*, supported either on the *housings* or an extension of the base; a *saddle* or saddles on the cross-rail, carrying one or more swiveling *boring heads*, which latter in turn may be equipped with a *turret*

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and *turret slides;* a driving mechanism for operating the table; and a feeding mechanism consisting of the various feed cones, gears and rods for controlling the movements of the heads and tools. Many of the smaller machines are equipped with screw-cutting devices and have universal chucks with independent jaws built into the table. The table is operated by means of a *driving cone* through the medium of *back gears* and a *bevel gear pinion* which engages in teeth on its periphery. A 30″ machine has a table 28″ in diameter which has 16 changes of speeds. The movement of the tool which is held in the head or turret, and which operates on the work fastened to the table, is controlled by the feed mechanism through the medium of the feed cones, gears and rods. The saddles, carrying the heads, turrets, etc., on the cross-rail, may be operated either automatically or by hand, as may also the slides and turrets. The heads may be swiveled at any angle to provide additional adjustment for the tool and to enable taper work to be turned. They are provided with an absolute center stop so that they may be run to the center of the table and clamped, in which position the Morse taper, with which they are provided, is concentric with the table, permitting the use of small drills, boring bars, etc., without the removal of the tool posts from the slide. In the 30″ machine the turret is 10″ in diameter and provided with four $2\frac{1}{2}$″ holes; the slide may be set at an angle up to 30° for boring and turning tapered work, and possesses a downward movement of 16″. The feeds, which are positive, range from $\frac{1}{40}$″ to $\frac{1}{4}$″ horizontally and from $\frac{1}{80}$″ to $\frac{1}{8}$″ vertically, are eight in number and are provided with *automatic trips.* The screw-cutting attachment provides a means of cutting from 4 to 12 threads per inch. With this machine a double-speed counter-shaft is provided.

923. Characteristic Operations. It is important to understand the following operations and adjustments of the boring and turning mill before starting to work:

(1) The correct method of adjusting the tools in the tool post or turret, also a knowledge of the turret movement together with the use of the socket and the method of removing the tool and bars from the spindle or tapers.

(2) The adjustments of the drive mechanism, back gears, etc., so that, after its determination, the correct speed may be given to the table and work.

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(3) The method of manipulating the saddles and heads so as to bring the tool into its proper relation with the work.

(4) The various methods of securing, after their determination, and of controlling the different feeds.

(5) How to throw in the automatic feeds, and the adjustments of the automatic trips.

(6) A thorough understanding of the screw-cutting mechanism and its change gears.

Boring

931. Preparation of the Work. The preparation of the work for the boring mill is similar to that required when castings are machined in the lathe. Very little, if any, laying out is necessary, the major part of the preparatory process being its adjustment in relation to the tool. As was the case with the lathe, the piece must be set central with the center of rotation, when it is blocked up and clamped, either on the table or in the chuck. For turning and boring flat work, what has been said relative to chucking such work in the lathe applies with equal force here. The center of such a piece is first bored, the top faced and as much of the outside turned as the jaws will permit, when it is turned over and again chucked to the finished portion and finished. When possible, drivers — devices to prevent the work from turning on the table — should be used in order to prevent slipping in the jaws, from the stress due to the tangential pressure of the tool. The principles here stated are fundamental, though the fastening of irregular pieces may call for some little ingenuity on the part of the operator.

932. Lathe-boring Operations. The operation of boring, after the work has been fastened, is comparatively simple. Considerable judgment should be used in the grinding and adjustment of the tool; the theoretical height of this tool is below the center for the same reason that for outside tools it is above the center. For other reasons, however, it is generally placed on the center and ground for scant clearance in this position. Where no hole is cored, the piece is countersunk with a special tool, and a hole drilled with either a flat chucking or an ordinary twist drill, the drill being held in a suitable holder. For boring long holes in spindles and the like, a hog, or half-round flat nose drill, is sometimes used. This drill is sometimes used as a bottoming drill.

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In this drill, one side of the cylindrical stock of which it is made is cut away, and the other left full size to act as a guide; this drill cannot be fed as fast as a twist drill on account of its having but one cutting edge. Where rough boring is desired in cored holes, a flat drill is used; the use of this drill necessitates a special holder which is clamped in the tool post.

The student should now read again what has been said about boring tools, Sec. 445, in Chapter 4 on "Cutting Tools" and related matter in Secs. 946 to 949. The roughing cut — which can never be very heavy on account of the spring of the tool — should be as heavy as possible. After taking the roughing cut, the hole should be calipered; if found to be tapered it will be necessary to use lighter cuts. Sometimes a tapered hole may be straightened by reversing the feed; this, however, is not good practice. Finishing cuts should always be light and taken with a fine feed. In turning a pulley, or the flange of a flange coupling, it is first chucked for boring and bored; after boring it is reamed and forced on an arbor on which it is subsequently finished. Where the pulley is small, it may be driven by means of a dog on the end of an arbor; where it is large, it is driven by a lug (termed a driver) bolted to the face-plate, which engages one of its arms.

933. Chucking — Adjustment in Chucks. The method of holding or adjusting in chucks is best adapted for work that is small and regular. The common form of lathe chuck consists of a heavy cast-iron disk, on the back of which is bolted a small face-plate, threaded to fit the lathe spindle. In the front or face of this disc radial slots are cut, through which jaws for holding the work are made to slide by means of screws. In fastening the chuck to the spindle it should be held carefully in position and the lathe *turned over by hand* until it starts on; no other way should be used. Never allow the chuck to come up to the shoulder with a bang. A chuck that is tight on the spindle may often be started by means of a wooden lever placed between the jaws. Sometimes this lever is so placed as to strike the lathe bed when the lathe is started backward at its slowest speed. Before assembling the chuck and the spindle, the threads on the spindle and in the chuck should always be wiped clean and oiled.

As the matter of adjusting and centering the work in independent and combination chucks is one of try and try, for trial the piece is clamped in the chuck and the spindle rotated slowly,

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while a piece of chalk or a tool held stationary near it gives indication of the amount it is out.

934. Adjustment on Face-plate. When the character of the work is such that it cannot be held in a chuck and can be swung, being either too large, too heavy or irregularly shaped, it is bolted directly to the face-plate. In fastening the work to the face-plate, bolts, U-clamps, strips and blocking are used in any manner to secure rigidity, the aim being to prevent the work from slipping during the operation of boring; in some instances angle plates are used. Where the work is such that when bolted to the face-plate it is unbalanced — more on one side of the center than on the other — it must be counterbalanced by bolting a suitable weight on the other side of the face-plate.

It is almost impossible to clamp two finished surfaces together so that they will not slip under the action of the boring tool; however, a piece of paper between the surfaces will prove efficacious in obviating this difficulty.

In all chucking and adjustment of the work, care should be taken to see that no projections interfere with either the carriage or the ways.

935. Adjustment on Carriage. This method of fastening the work for machining is resorted to when no other method is available. Care must be taken that the work be fastened securely, as any movement or derangement in adjustment will entail a loss of considerable time; paper between finished surfaces will again prove effective. It is evident that when the work remains stationary the tool must revolve, and to this end boring bars are used. A boring bar is generally a shaft, carrying either a fixed cutter or a sliding cutter head which carries the cutting tools.

936. Order of Operations for Lathe Boring. The order of procedure for boring in the lathe, after the work is placed, is similar to the order of operations for straight turning in Chapter 8, Sec. 842, and the workman is advised to follow the order given there.

937. Order of Operations for Mill Boring.

(1) *Adjust the work.* The adjustment of the work is rather a simple operation as compared with its adjustment on the face-plate of a lathe, it being manifestly easier to lay a piece down than it is to hang it up; and again to secure it when the weight of the piece is carried by the machine and not on the securing

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device. The work as it can be, should be trued before the final clamping, the horizontal position of the table providing a ready means of adjusting the bolts, straps and jacks. Irregular shapes such as eccentric discs, offset valves, etc., require no counterbalancing, while for manufacturing purposes jigs and fixtures, for securing and locating castings, are easily attached to the table.

(2) *Adjust the tool.* Select and adjust the tool, noting that it is properly ground and whetted. A set of boring tools consists of a boring tool, five turning tools, a bar, a 4-lipped drill, a loose reamer shank and shell reamer and a tool-holder.

(3) *Adjust the slide and saddle.* Bring the head and saddle into their proper relation with the work, the tool just over the edge of the surface to be operated upon.

(4) *Determine the speed and feed.* Calculate it or consult the material in Chapter 4, and then adjust the belts and gears to obtain this speed and feed.

(5) *Adjust for travel and feed.* Adjust the automatic trip dogs so as to stop feeding at the proper time, and the feed mechanism — coarse or fine as the work in hand demands — so as to obtain a maximum output.

(6) *Pull over by hand.* With all adjustments made, and the tool in its position, pull over by hand to determine the accuracy of the adjustments and to avoid breakage.

(7) *Start the machine.* Start the machine and feed the tool by hand until the desired depth of cut is obtained.

(8) *Throw in the feed.* Throw in the automatic feed and watch the work carefully to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time.

Chucks, Boring and Chucking Tools

941. Chucks. As has been stated, the common form of lathe chuck consists of a heavy cast-iron disc, on the back of which is bolted a small face-plate, threaded to fit the lathe spindle. In the front or face of this disc, radial slots are cut, through which jaws, for holding the work, are made to slide by means of screws.

Chucks are classified, according to the number of jaws and the method of their adjustment, into independent, universal and combination, each kind having either two, three or four jaws as desired.

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942. Independent Chucks. An independent chuck is so arranged that each jaw may be moved, with its separate adjusting

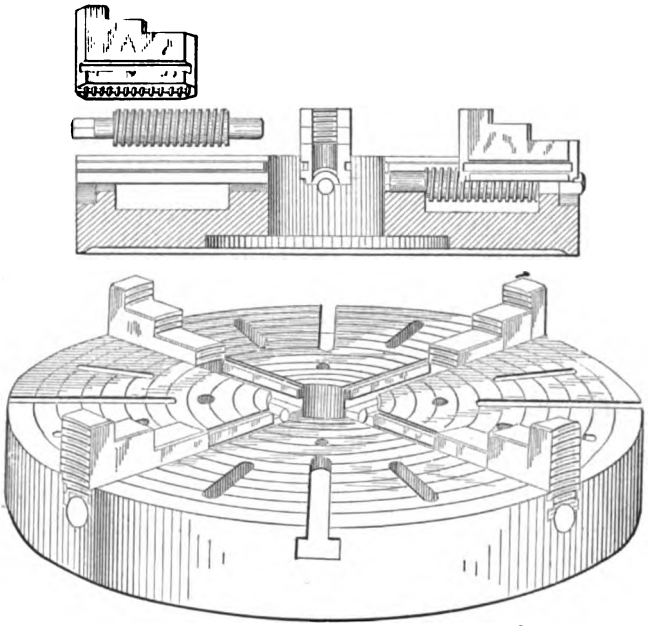

FIG. 942. — Independent Four-jaw Chuck.

screw, independently of the other jaws. This style of chuck is best adapted to heavy work and work of irregular shape.

943. Universal Chucks. The universal chuck is constructed

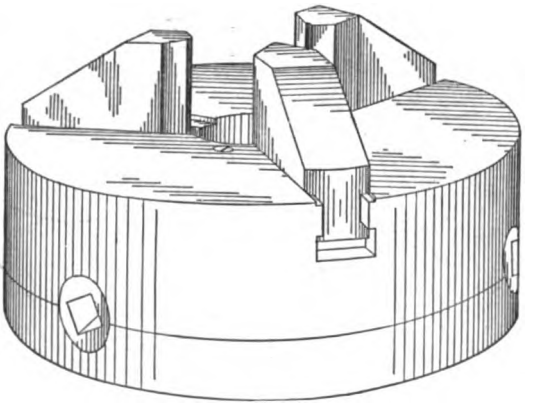

FIG. 943. — Universal Geared Scroll Chuck.

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in such a manner that when any one jaw is moved, the others move simultaneously in the same direction, a like distance. These chucks are best adapted to regular work, as a great saving of time is effected by the ease and rapidity with which such work may be centered.

944. Combination Chucks. The combination chuck, as its name indicates, is a combination of the other two, with its jaws

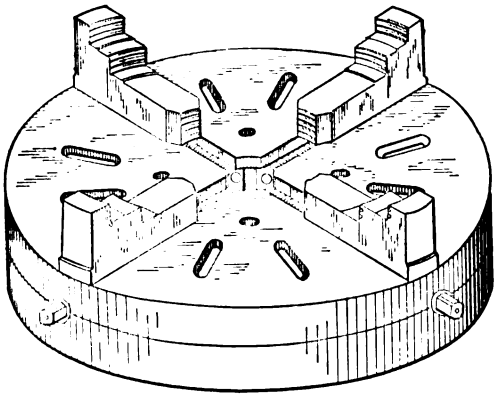

FIG. 944*a*. — Combination Chuck.

moving independently or simultaneously as desired. Owing to its greater complexity, this chuck requires a little more care in handling; it is used both for regular and irregular work.

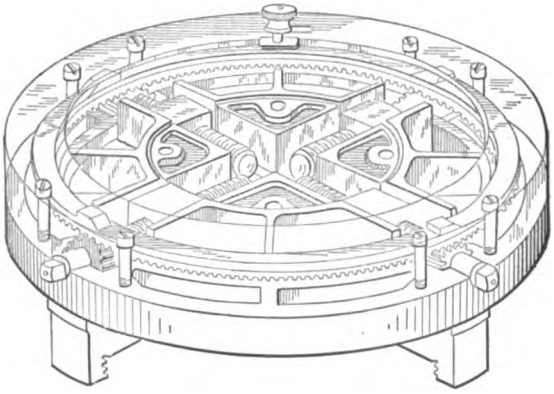

FIG. 944*b*. — Section of Skinner Combination Chuck.

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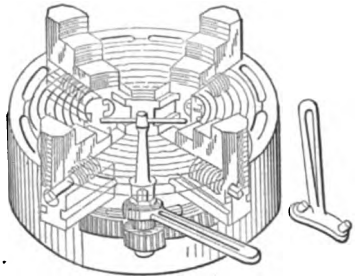

FIG. 944c. — Westcott Spur-geared Scroll Combination Chuck.

945. Care of Chucks. As the value of a chuck is dependent upon its ability to hold the work firmly and true, it should never be abused by hammering or straining. Repeating the points noted in Sec. 933: In fastening a chuck to the spindle, it should be held carefully in position and the lathe turned over by hand until it starts on; no other way is to be used. Never allow the chuck to come up to the shoulder with a bang. A chuck that is tight on the spindle may be removed by putting a stick of wood between the jaws of the chuck and the lathe bed, and starting the lathe backward at its slowest speed. Before putting on the chuck, see that the threads on the spindle and in the chuck are clean; they should always be wiped and oiled.

946. Boring Bars and Cutters. In boring, when it is necessary that the work be stationary, the tool must revolve, and to this end boring bars are used. A boring bar is generally a shaft carrying either a fixed cutter or a sliding cutter head which carries the cutting tools.

In the drawings, Fig. 946*a* and Fig. 946*b* illustrate types of boring bars, while Fig. 946*c* shows a common form of cutter head. Fig. 946*b* shows one method of fastening the cutters in a boring bar. The pin is made of cast steel, turned to a taper of $\frac{1}{2}''$ to the foot, and hardened. The front edge of the cutter is so placed that it will cover about one half of the diameter of the pin hole, and the part of the cutter that covers the hole is filed away almost entirely, leaving just sufficient stock for the pin to press against when it is driven in tight. The cutters are turned while in this position, then taken out, hardened, replaced and ground to size. A number can be made at one time and kept in stock, being first carefully marked.

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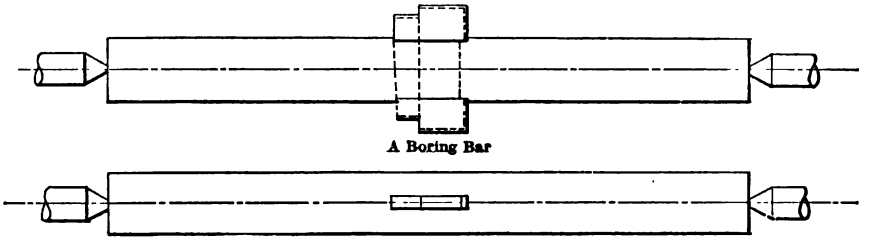

FIG. 946*a*. — A Common Boring Bar.

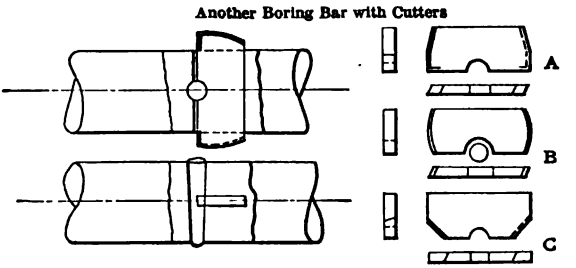

FIG. 946*b*. — Another Bar with Cutters.

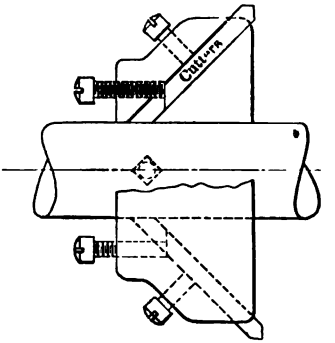

FIG. 946*c*. — A Cutter or Boring Head.

A set of cutters for this bar is shown at the right of the bar, Fig. 946*b*. *A* is a roughing cutter and is held in the bar in the manner shown. Sometimes two roughing cuts are necessary for each hole, thus requiring two roughing cutters. About .025″ is left for the finishing cutter, *B*, whose form is shown with rounded cutting edges. It is placed in the same slot as *A*, but the semi-circular groove in it is enlarged so that when the cutter is in its

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place the pin does not come in contact with it, the pin being used in this case merely to prevent the cutter from falling out of the bar previous to its entering the hole. Cutter *C* is used for countersinking or chamfering the opening; this is generally done before the finishing cut is taken.

947. Chucking Drills. Chucking drills are made in a variety of styles and shanks, the most noticeable variation from the ordinary twist drill being a provision for conveying a lubricant to the point of the drill. Ordinarily a small circular oil hole, connected with a hollow shank, passes through the lands of the drill to the point or lips. For drilling cored holes, three- or four-groove drills are used; this class of drill is never used for drilling solid stock; should it be desired to use it, however, it should follow the ordinary two-groove twist drill. Two-groove twist-drills should never be used in cored holes, or for following another drill. See Figs. 947 *a*, *b* and *c*, pages 234–5.

948. Counterbores. Counterboring may be termed the annular enlargement of the upper end of a hole; the space between the two circumferences forming a shoulder, that is, giving to the enlarged portion parallel sides and a flat bottom. Counterbores, like other small tools, are made in a variety of styles, sizes and shapes. Common commercial bores are provided with straight or taper shanks, having at the cutting end a pin or guide, which is inserted in the hole to be counterbored. (Fig. 948, page 235.) The guides of standard counterbores are made either for the body size hole or for the tap drill hole, while the diameter of the counterbore is made for the screw head or for the body of the screw. Another form of counterbore is made by inserting and securing a tool steel cutter of proper sweep in a rectangular hole, in a round bar — oftentimes the ordinary boring bar.

949. Chucking Reamers. Chucking reamers, like chucking drills, are sometimes provided with means for conveying a lubricant to the cutting lips. For boring and reaming deep cored holes, the fluted portion of these reamers is $\frac{1}{64}''$ under size and is generally made with three grooves. Straight fluted chucking reamers, with a number of flutes, are made in standard sizes with a rose end or with straight ends in sizes .005 less than the nominal diameter. See Figs. 949 *a* to *j*, pages 235–6.

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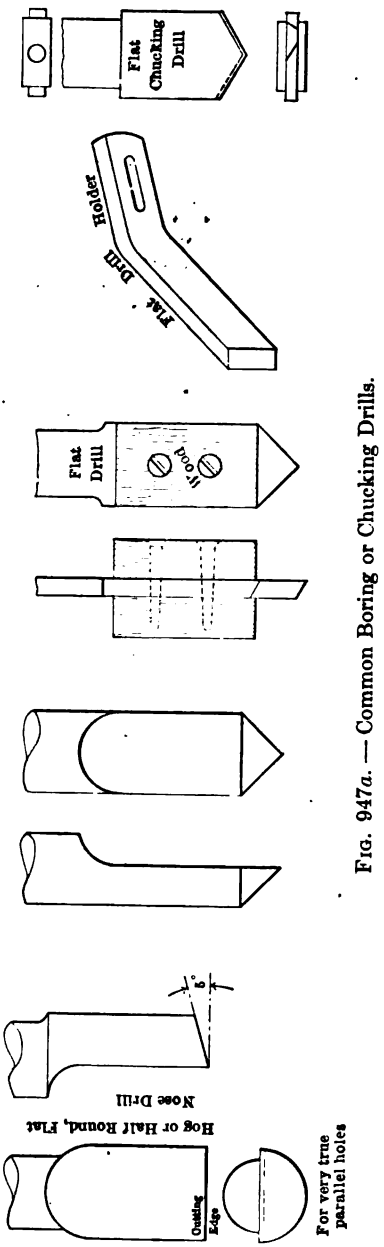

Fig. 947*a*. — Common Boring or Chucking Drills.

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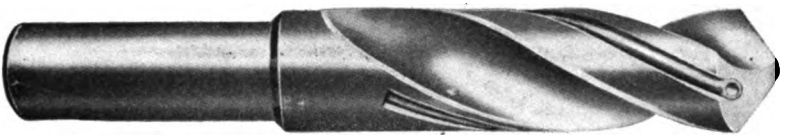

FIG. 947*b*. — Oil Tube Drill, Short Set.

FIG. 947*c*. — Oil Tube Drill, Long Set.

FIG. 948. — Combination Counterbore.

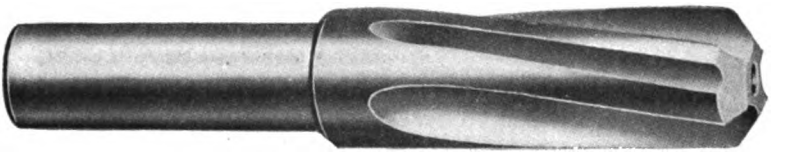

FIG. 949*a*. — Three-fluted Chucking Reamer, Short Set.

FIG. 949*b*. — Three-fluted Chucking Reamer, Long Set.

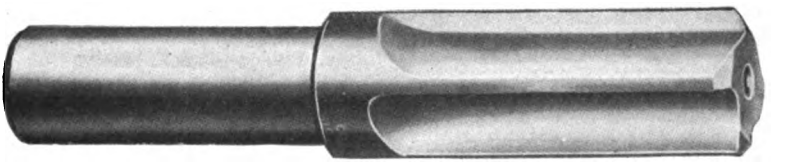

FIG. 949*c*. — Four-fluted Chucking Reamer, Short Set.

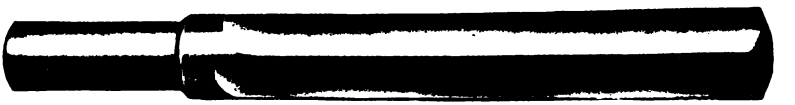

FIG. 949*d*. — Four-fluted Chucking Reamer, Long Set.

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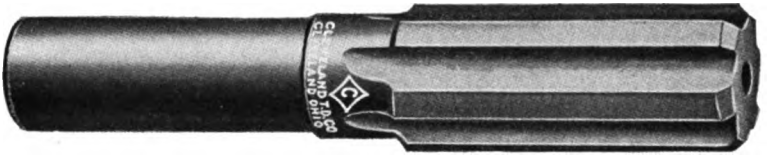

FIG. 949*e*. — Rose Chucking Reamer, Short Set.

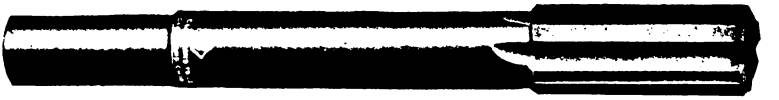

FIG. 949*f*. — Rose Chucking Reamer, Long Set.

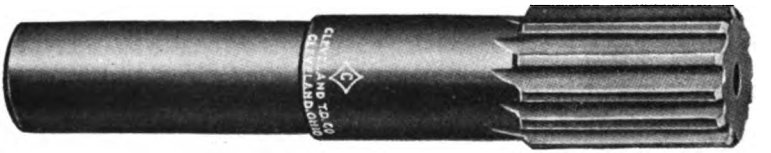

FIG. 949*g*. — Fluted Chucking Reamer, Short Set.

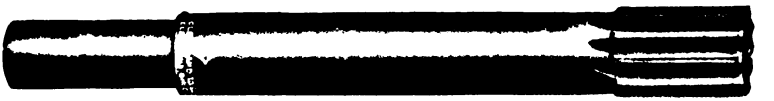

FIG. 949*h*. — Fluted Chucking Reamer, Long Set.

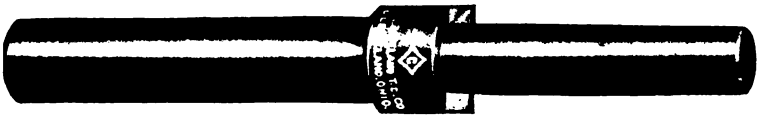

FIG. 949*i*. — Shell Reamer Arbor, Short Set.

Fig. 949*j*. — Shell Reamer Arbor, Long Set.

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CHAPTER X

DRILLING

Drilling Machines

1011. Drilling Machines and Operations. There are several types of drilling machines on the market; the smaller sizes being termed sensitive or sensitive friction drills; the medium or heavy sizes are usually termed upright drills; while the terms radial, universal, multiple spindle, adjustable spindle, flange, portable and pneumatic — usually portable— are all descriptive adjectives applied to the various kinds of drilling machines.

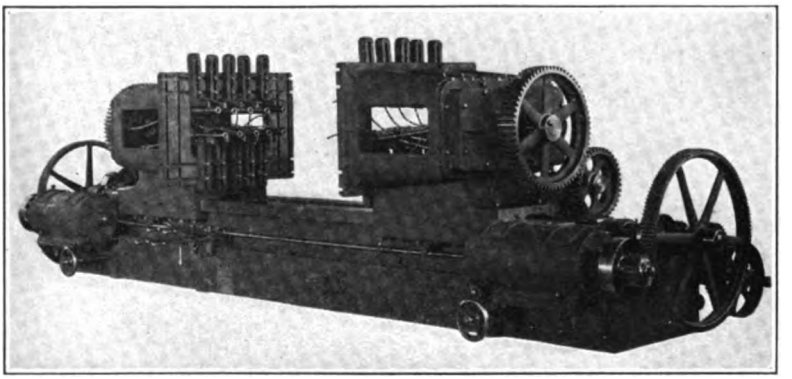

Fig. 1011. — Baush 16-spindle Double-head Drilling Machine.

The use of drilling machines has extended from the mere work of making round holes in metals, until now it includes such operations as: *countersinking* — a tapering enlargement of the upper end of a hole; *counterboring* — an annular enlargement of the upper end of the hole, the space between the two circumferences forming a shoulder; *reaming* — passing a reamer through a hole to obtain accuracy and to overcome imperfections; *tapping* — threading the inside of a hole; and *spot-facing* — a very shallow counterbore, barely deep enough to form a smooth shoulder for the head of a nut of a bolt.

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1012. The Sensitive Friction Drill. A type of this drill consists of the following essential parts: a *base* supporting the column and driving mechanism; a *column* which supports the table, spindle and feeding device; a movable *table* on which the work may be bolted; a *spindle* designed to receive and rotate the drill;

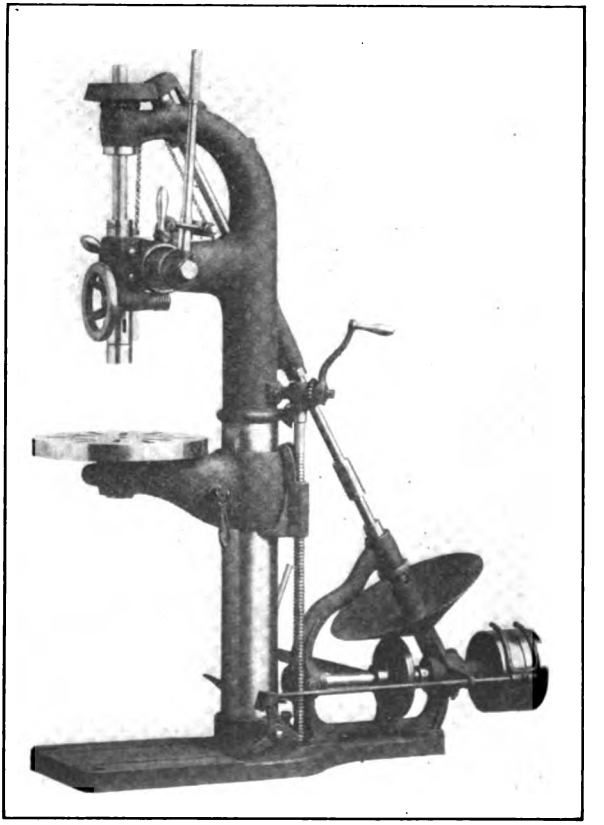

FIG. 1012. — Sensitive Friction Drill.

a *lever feed* for raising or lowering the spindle; a *friction disc and wheel* for changing the speed of the drill; and a *tight and loose* pulley for driving the machine.

In this drill the friction or speed-changing device consists of an iron disc and a leather-rimmed wheel which may be moved across its surface by means of a treadle. The leather-rimmed

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wheel receives its motion from the driving pulley, transmitting it through the friction disc to an oblique shaft, through bevel gears to the spindle.

The spindle, at whose side is a ratchet feed lever, contains at its lower end a taper hole to receive the drill shank. A slot through the spindle crosses the upper end of the taper, through which a drift or key is passed to force the drill from the spindle. The table, which is adjustable vertically and about its center, may be swung around the column and clamped in any desired position. This machine having a maximum capacity of $\frac{1}{2}''$ holes, is designed for such small, light work as may be held in the hand, "V" chuck or vise. By equipping the table with a center, it may be used advantageously for center drilling and countersinking.

1013. The Upright Drill. The upright drill is designed for drilling holes in the larger, heavier and irregular work of the

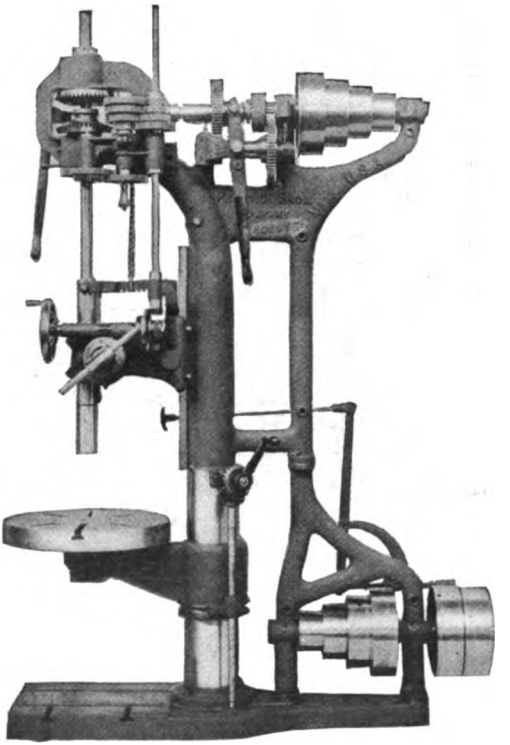

FIG. 1013*a*. — Prentice 28" Upright Drill with Tapping Attachment.

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ordinary machine shop. While it is true that the lathe is often used advantageously for drilling holes in pieces already, or easily chucked, the medium-sized drill is better adapted for drilling holes in most of the ordinary work of the shop.

A common type of this drill consists of the following essential parts: a *base* supporting the column, tight and loose pulley, and

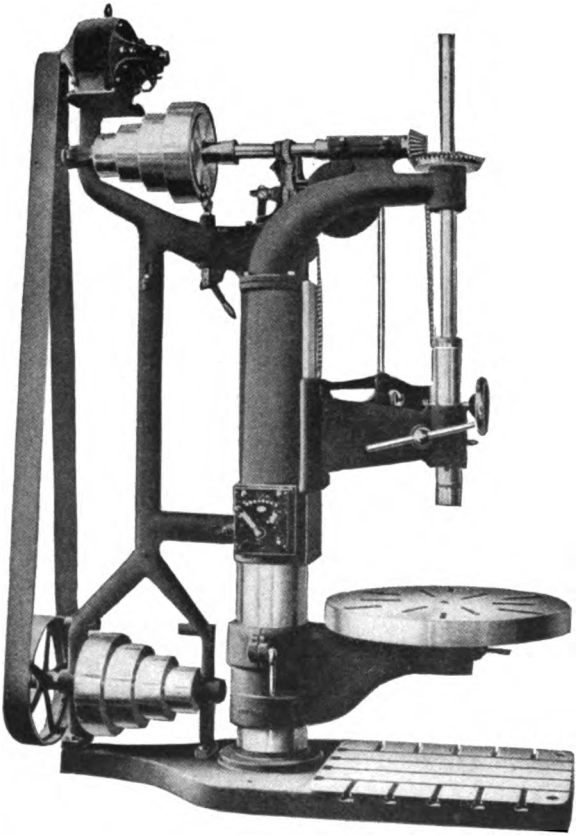

FIG. 1013*b*. — Barnes Electrically Driven Upright Drill.

speed cone; a *column* which supports the table, the sliding head, the upper cone, back gears, spindle and feed mechanism; a movable *table* on which the work is placed or bolted; a *spindle* designed to receive and rotate the drill; *cone pulleys* and *back gears* for changing the speed of the drill; a *sliding head* containing a variable

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power or *hand feed* equipped with *automatic stop* and *quick return;* a device for raising or lowering the sliding head; a device for raising or lowering the table; and a *tight and loose pulley* for driving the machine.

The vertical spindle, the lower end of which contains a taper hole for receiving the drill shanks, is rotated from its upper end by means of bevel gears from the horizontal shaft which carries the back gears and cone pulley. Both of these latter afford means of varying the speed of the spindle. The cone pulley above is driven by a similar cone on the shaft with the tight and loose pulleys situated near the base of the machine. The upper cone pulley contains the back gears, which may be thrown into or out of action by means of a suitable lever. This lever should never be touched while the machine is in motion. Directly underneath the spindle, fastened to the column, around which it may be swung, is a horizontal table to which the work may be clamped or bolted. This table, which is adjustable vertically, may be rotated about its axis as well as about the axis of the column. The spindle has a vertical movement for feeding the drill, which may be operated while running, either automatically or by hand. A lever and wheel to the side of the spindle are provided for feeding by hand; the power or automatic feed is operated by means of a small cone pulley and worm gears, and is equipped with suitable latches and stops for throwing it into or out of action. In addition to the spindle adjustment for feeding, in many machines the construction is such that the entire spindle and its feed mechanism may be adjusted vertically on the column; when this is the case the drill is said to have a sliding head. The spindle, like that of most drills, contains at its lower end a taper hole to receive the drill shanks. A slot through the spindle crosses the upper end of the taper, through which a drift or key is passed to force the drill from the spindle.

The advantage of this drill over the sensitive drill lies not only in the increased capacity and adjustment, but in the fact that very heavy, irregular or awkward-shaped pieces may be easily adjusted and clamped in position. When using this machine it is good practice to bolt the work securely to the table or base, both of which are slotted for this purpose. Long bars, "V"-blocks — for holding round pieces — the drill vise and similar articles should invariably be bolted to the table, both to insure accuracy

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and to avoid accident. The lubrication of a drill is more easily effected when it is held vertically in a spindle than when held horizontally in a lathe, for the reason that in the former case the oil feeds by gravity into the cutting lips.

1014. Radial and Universal Drills. The radial drill is designed to drill holes in such large or irregular work as cannot be

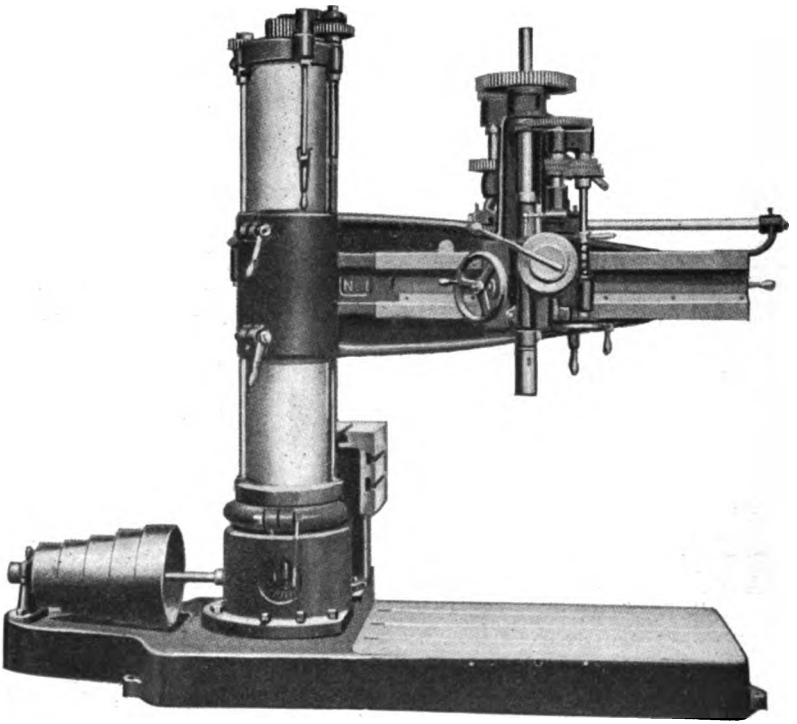

FIG. 1014*a*. — Bickford Plain Radial Drill.

readily placed or bolted on the base or table of the medium upright drill. A common type of radial drill consists of a *base* — provided with an extension table — supporting the column and speed box; a *column* which supports the arm and some of the speed and feed mechanism; a horizontal *arm* carrying the head, feed mechanism and rods; this arm may be raised or lowered either by hand or automatically and may be swung in a full circle around the column. The horizontally *sliding head* carries

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the drill spindle (designed to receive and rotate the drill), the feed box, trip mechanism, speed and feed plate, and the various operating levers. The *speed box* attached to the base is designed to take the place of the cone pulley and provides four speeds instantly by means of a single lever. The *feed box* attached to the head provides, in connection with the back gears, sixteen feeds

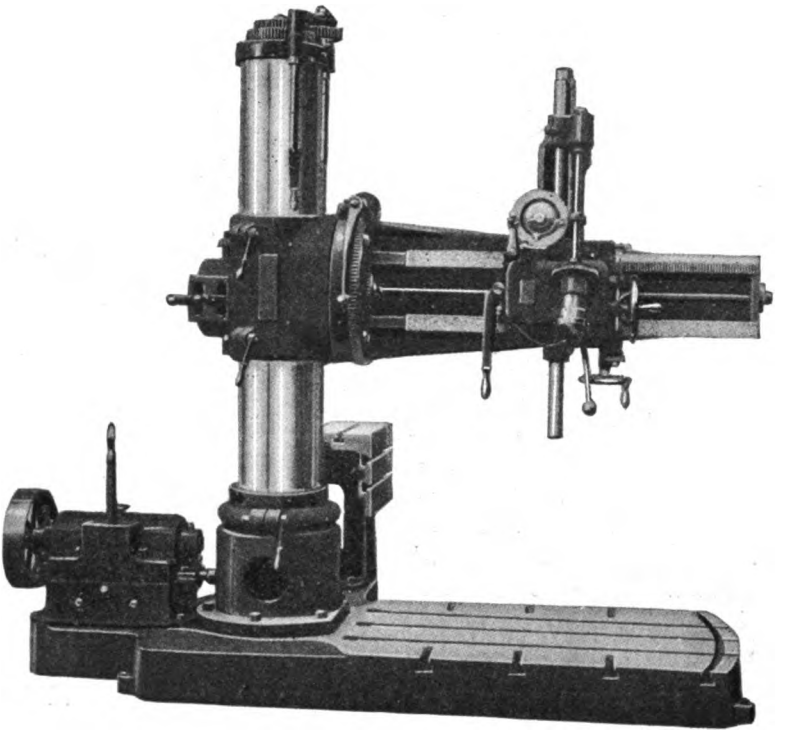

FIG. 1014*b*. — Bickford Universal Radial Drill.

without stopping the machine. The eight feeds, arranged in a geometrical progression ranging from .007″ to .064″ per revolution of the spindle, are operated either automatically or by hand, while the spindle is provided with an automatic stop. For such large work as cannot be supported on a universal table, the arm and head are designed to swivel in such a manner that the drill spindle may operate at any angle in any direction; when this is the case we have the *universal radial drill.* The operation of the

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radial drill does not differ materially from that of other drills, though the advantages of such a machine tool are obvious.

Drilling

1021. Preparation of Work — Laying Out. Chalk the surface to be drilled and determine the position of the hole by measuring from the center lines or a finished surface, locating the exact center of the hole by means of a light center punch mark. About this center describe with the dividers a circle whose diameter is equal to that of the hole desired. On the circumference of this circle make a few — four, six or eight — light punch marks at equal intervals. The object of the punch marks being to give permanence to the circumference, so that the drill may be brought to the proper center after the original center punch mark has been cut away. On machined surfaces it is often better to describe a circle, slightly larger in diameter than the hole required, from the center punch mark and to center the drill from this circle.

When a number of similar pieces are to be drilled, drill jigs or templets are used to obviate the expensive operation of accurately laying out and drilling holes by the method outlined above.

A hole that is subsequently to be threaded by tapping is usually marked thus: $\frac{7}{16}''$ — 14 Thd. When a hole is so marked, the tap drill for this thread should be used, the tap drill, of course, being one a trifle larger than the diameter at the bottom of the threads. The sizes of tap drills for U. S. standard threads are given in the table of "U. S. Standard Thread Bolt and Nut Data," Sec. 671, in the chapter on "Screw and Pin Data."

1022. Characteristic Operations. It is important to understand the following operations and adjustments of the drilling machine before starting to work:

1. The correct method of grinding the drill and of holding it in the spindle or chuck; also the use of the socket and the method of removing the drill from the spindle.

2. The adjustment of the drive and feed belts and the back gears so as to attain, after calculation, the correct speed and feed.

3. The method of manipulating the table so as to bring the center punch mark on the work directly underneath the drill and of clamping it in this position.

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4. The various methods of feeding by means of the lever for small holes, by using the hand wheel, and automatically by throwing in the latch.

5. The method of reading the depth scale to obtain the proper depth of hole.

6. The manner in which the automatic stop block is adjusted to throw the latch which, in turn, stops the feed at the desired depth.

7. How to "throw" the drill. A drill that is off center may be drawn back with the center chisel. A groove is chipped, quite near the center, down the side toward which the drill point is to be drawn.

8. How to raise the drill spindle while running. This is effected by throwing out the feed, grasping the latch handle on the long lever with the right hand and raising the spindle with the short lever in the left hand.

1023. Order of Operations. Observe the following order of procedure when operating the machine drill.

1. *Adjust the work and table.* Bolt or clamp the work to the table; if held in a vise, the vise should be bolted to the table. Select the proper drill, wipe both taper and socket clean, and insert in the spindle. Swing the drill table about, and adjust the center mark of the hole until it is directly underneath the drill point, making sure that the point coincides with the center.

2. *Fasten the table.* Clamp the table for position at its center, and for height on the column.

3. *Determine the speed and feed.* Consult the table (Fig. 1024) and the data in Secs. 424, 428 and 429. Adjust the belts to give the proper speed and feed; *i.e.*, the ones selected.

4. *Pull over by hand.* With the adjustments made, pull over by hand to determine their accuracy.

5. *Start the drill.* After starting the machine, feed the drill slowly by hand; when the point of the drill has entered the work to about half its depth, raise the spindle, blow out the chips, and examine to see if the drill is cutting in the center of the circle. If the drill has run off it must be drawn back; this is accomplished with a center chisel — a light, narrow, round-nosed chisel — with which the metal is cut away on the side toward which the drill point is to be drawn. A groove is chipped down the side, quite near the center, because metal removed there will draw the drill

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farther than when the chipping is done nearer the circumference. If the error is great, readjust the table. Now lower the spindle, drill the hole a little deeper and correct in the same manner until the proper adjustment is had. All corrections must be made before the full diameter of the drill enters the metal.

6. *Read depth scale.* Note the reading of the depth scale, and if several holes of the same depth are to be drilled, adjust the automatic stop.

7. *Throw in feed.* The automatic feed should be thrown into action after the work has been accurately located, and the work carefully watched to detect any error or movement that may occur.

8. *When through, raise drill spindle.* This may be quickly done, as stated above, by throwing out the feed, grasping the latch handle on the lever with the right hand and raising the spindle with the short lever in the left hand.

1024. The Speed of Drills. The following data is recommended by the Cleveland Twist Drill Co. as being applicable to the ordinary commercial drills. A feed per revolution of .004″ to .007″ for drills ¼″ or smaller and from .007″ to .015″ for larger is about all that should be required. This feed is based on a peripheral speed of a drill equal to 30 feet per min. for steel; 35 feet per min. for iron; and 60 feet per min. for brass. It may also be found advisable to vary the speed somewhat according as the material to be drilled is more or less refractory. The speeds given in the table (Fig. 1024) should not be exceeded under ordinary circumstances.

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TABLE OF CUTTING SPEEDS FOR DRILLS

Ft. per Min.	15′	20′	25′	30′	35′	40′	45′	50′	60′	70′	80′
Diam.	Revolutions per Minute										
1/16 in.	917.	1223.	1528.	1834.	2140.	2445.	2751.	3057.	3668.	4280.	4891.
1/8	459.	611.	764.	917.	1070.	1222.	1375.	1528.	1834.	2139.	2445.
3/16	306.	408.	509.	611.	713.	815.	917.	1019.	1222.	1426.	1630.
1/4	229.	306.	382.	458.	535.	611.	688.	764.	917.	1070.	1222.
5/16	183.	245.	306.	367.	428.	489.	550.	611.	733.	856.	978.
3/8	153.	204.	255.	306.	357.	408.	458.	509.	611.	713.	815.
7/16	131.	175.	218.	262.	306.	349.	393.	437.	524.	611.	699.
1/2	115.	153.	191.	229.	268.	306.	344.	382.	459.	535.	611.
9/16	91.8	123.	153.	184.	214.	245.	276.	306.	367.	428.	489.
3/4	76.3	102.	127.	153.	178.	203.	229.	254.	306.	357.	408.
7/8	65.5	87.3	109.	131.	153.	175.	196.	219.	262.	306.	349.
1	57.3	76.4	95.5	115.	134.	153.	172.	191.	229.	267.	306.
1 1/8	51.0	68.0	85.0	102.	119.	136.	153.	170.	204.	238.	272.
1 1/4	45.8	61.2	76.3	91.8	107.	123.	137.	153.	183.	214.	245.
1 3/8	41.7	55.6	69.5	83.3	97.2	111.	125.	139.	167.	195.	222.
1 1/2	38.2	50.8	63.7	76.3	89.2	102.	115.	127.	153.	178.	204.
1 5/8	35.0	47.0	58.8	70.5	82.2	93.9	106.	117.	141.	165.	188.
1 3/4	32.7	43.6	54.5	65.5	76.4	87.3	98.2	109.	131.	153.	175.
1 7/8	30.6	40.7	50.9	61.1	71.3	81.5	91.9	102.	122.	143.	163.
2	28.7	38.2	47.8	57.3	66.9	76.4	86.0	95.5	115.	134.	153.
2 1/4	25.4	34.0	42.4	51.0	59.4	68.0	76.2	85.0	102.	119.	136.
2 1/2	22.9	30.6	38.2	45.8	53.5	61.2	68.8	76.3	91.7	107.	122.
2 3/4	20.8	27.8	34.7	41.7	48.6	55.6	62.5	69.5	83.4	97.2	111.
3	19.1	25.5	31.8	38.2	44.6	51.0	57.3	63.7	76.4	89.1	102.

FIG. 1024.

DRILLS

1031. Characteristics of a Drill. Of the several forms of drills used in the machine shop, the primitive, simply made flat drill is the cheapest and easiest to make, while the twist drill, possessing most of the advantages and few of the defects of the other types, has come into almost universal use. The essential characteristics of a drill are as follows: (1) It must have one or more cutting edges. (2) It must have a central guiding or leading point; this leading point is usually secured by grinding the cutting edges at an angle with the axis of the drill, generally between 50 and 60 degrees. (3) The cutting edge must have ample clearance. (4) There must be a suitable shank for holding the drill.

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1032. The Flat Drill. In order that the flat drill may produce accurate work, it is essential that the cutting end be symmetrical in every respect. Improperly formed edges tend to produce holes that are out of position, rough, oblique, holes that are larger than intended and holes not round. From a glance at

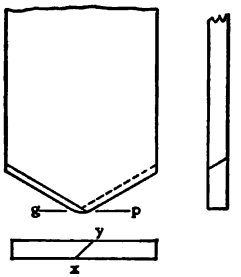

FIG. 1032. — Flat Drill.

the drawing (Fig. 1032) it will be seen that the planes representing the clearance angles intersect in a line perpendicular to the axis of the drill, and that when the drill is rotated, the action here is a scraping instead of a cutting one. It becomes evident that the best results will be obtained when this scraping edge is short; therefore, the thinner the drill, when sufficient thickness is had to support the cutting edges, the better.

1033. The Lipped Drill. In this drill, in order to produce keenness and to give what, in a lathe tool, would be called top

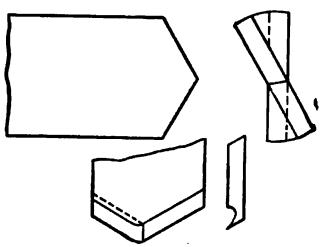

FIG. 1033. — Lipped Drill.

rake, the cutting edge is ground as shown in the drawing. What is still better is to twist it as shown in the other drawing; this produces a spiral that assists in carrying the chips away from

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the cutting edge, anticipating, in some respects, the ordinary twist drill.

1034. The Scraping Edge Drill. The point of this drill is similar to that of the ordinary flat drill, with the exception that

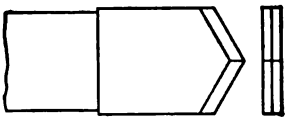

FIG. 1034. — Scraping Edge Drill.

it is ground for clearance on both sides, producing an edge similar to that of a cold chisel. The one advantage of this drill lies in the fact that it works equally well backward and forward.

1035. The Half-round or Hog-nose Drill. In this drill one side of the cylindrical stock of which it is made is cut away and the other half is left the full size of the hole to act as a guide. The cutting edge should be ground perpendicular to the axis

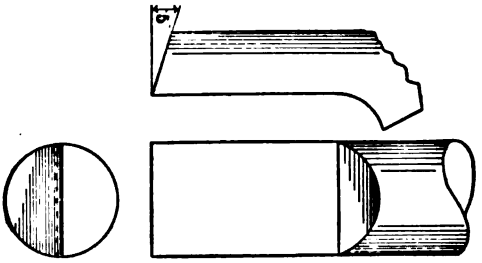

FIG. 1035. — Half-round or Hog-nose Drill.

of the drill and be given a clearance of 5°. It is important that this drill, as it possesses no central leading point, be started true; when this is done a hole of any depth may be bored smooth and true. Some authorities state that for boring parallel accurate holes this drill is unsurpassed. This drill may also be used for squaring the bottom of holes drilled with drills having a central leading point.

1036. The Modified Hog Nose. — "D" Drill. A modification of the hog-nose drill is shown in the figure. This drill in its simplest form consists of a round bar of the diameter of the hole required, one side of the end of which is relieved — cut away

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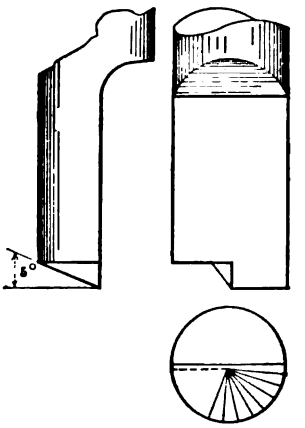

FIG. 1036. — Modified Hog Nose — "D" Drill.

— to give clearance; in other respects this drill is similar to the hog-nose drill described above. This drill in some one of its modifications is generally used for boring lathe spindles, hollow shafts, guns and the like. What has been said in reference to the grinding and operation of the hog-nose drill applies with equal value to this modification of it.

1037. The Straight-fluted Drill. The commercial drill of this variety is made of round stock generally, with two straight flutes

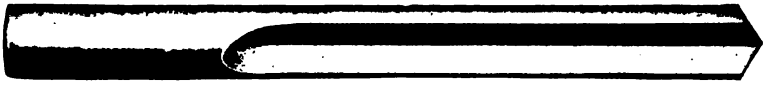

FIG. 1037*a*. — Straight Shank Straight-fluted Drill.

FIG. 1037*b*. — Taper Shank Straight-fluted Drill.

running parallel to the axis of the drill. This drill is usually ground similar to the twist drill or flat drill and possesses advantages over them for the softer metals such as babbitt and the copper alloys. A straight-fluted drill will be found excellent for drilling thin plates and similar work.

1038. The Twist Drill. Ordinary twist drills are made of round stock and helical fluted with a milling cutter. To prevent

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undue friction on the sides of the hole, the metal between the flutes is backed off in one of the ways shown in Fig. 1038*b*; just

FIG. 1038*a*. — Taper Shank Twist Drill.

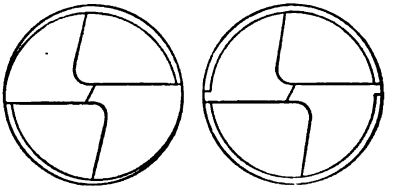

FIG. 1038*b*. — Method of Relieving Drill Lands.

enough surface is left, however, to form a bearing and guide for the drill. What has been said of the irregularities produced by the imperfect grinding of flat drills applies with equal force to twist drills. By the use of a drill grinder these difficulties are almost entirely obviated.

1039. Special Drills, Countersinks and Reamers. The following group of half-tones, Figs. 1039*a* to 1039*f*, together with their designations, will give the reader some idea of the various commercial specialties to be had of the drill makers.

FIG. 1039*a*. — Flat Drill with Ratchet Shank.

FIG. 1039*b*. — Taper Shank Left-hand Twist Drill.

FIG. 1039*c*. — Straight Shank Oil Groove Twist Drill.

FIG. 1039*d*. — Bit Stock Countersink.

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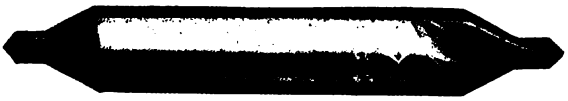

FIG. 1039*e*. — Combined Drill and Countersink.

FIG. 1039*f*. — Center Reamers.

DRILL SHANKS, SOCKETS AND COLLETS

1041. Drill Shanks. There are several styles of drill shanks in ordinary use; the most common, however, are the straight and taper shanks. The taper shank drills, while more costly than the straight shank, possess many advantages over them; when inserted in a socket they will not drop out; wear in the drill spindle does not necessarily produce a derangement of the cutting edges of the drill; and in a properly fitted, clean socket the drill is always tight. At the end of the taper shank — at the top — a flat portion or tang fits into a slot in the spindle and prevents the drill from turning in the socket. The tapers in common use are the Morse tapers, numbered from one to six inclusively, having the dimensions given in the following table. (Fig. 1042.)

Note. The Morse taper was intended to be $\frac{5}{8}''$ per foot, but unfortunately the first standards were incorrect, and consequently the different numbers of the Morse tapers are not the same, and no one of them is exactly $\frac{5}{8}''$ per foot as was originally intended.

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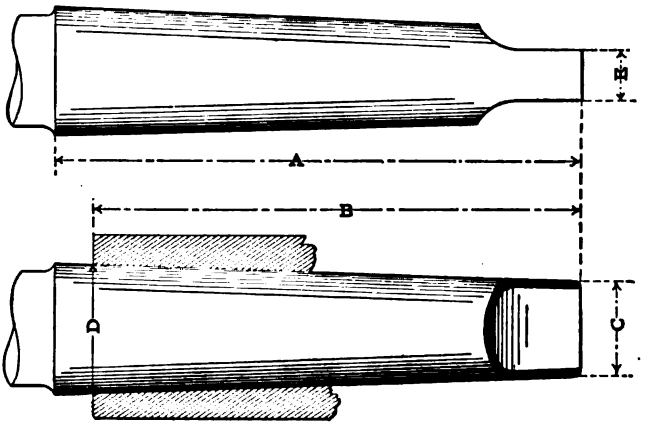
1042. Morse Taper Shanks. Dimensions in Inches.



DIMENSIONS

NO.	A	B	C	D	E	TAPER IN 12 INCHES
1	$2\frac{11}{16}$ in.	$2\frac{7}{16}$ in.	.353 in.	.475 in.	$\frac{13}{64}$ in.	.600 in.
2	$3\frac{3}{16}$	$2\frac{15}{16}$	.553	.700	$\frac{1}{4}$	.602
3	$3\frac{15}{16}$	$3\frac{11}{16}$	.753	.938	$\frac{5}{16}$	.602
4	$5\frac{1}{8}$	$4\frac{5}{8}$	.991	1.231	$\frac{15}{32}$	.623
5	$6\frac{3}{8}$	$5\frac{7}{8}$	1.440	1.748	$\frac{5}{8}$	.630
6	$8\frac{3}{4}$	$8\frac{1}{4}$	2.064	2.494	$\frac{3}{4}$	.626

FIG. 1042. — Standard Morse Tapers.

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1043. Drill Sockets and Collets. Because all sizes of drills are not made with the same size of taper shank, drill sockets or collets are used. Drill sockets are tapered bushings, the outside being made to fit one size of taper shank drills, and the inside another size of taper. Collets are used for holding taper shank drills in spindles intended for straight shanks, and *vice versa*. By inserting a drift or center key, whose taper is $1\frac{1}{4}''$ per foot (8° 19′), in a suitable hole provided in the spindle and sockets the drill may be forced out of them. (Figs. 1043 *a*, *b*, *c*, *d* and *e*, show the various drill sockets and collets, and the method of removing the drill from the spindle or socket.)

FIG. 1043*a*. — Rough Drill Socket.

FIG. 1043*b*. — Fitted Taper Shank Drill Socket.

FIG. 1043*c*. — Sleeve or Shell Socket or Collet.

DRILL CHUCKS

1051. Light Drill Chucks. For the smaller straight-shank drills, and for light drilling, some form of drill chuck affords an excellent method of holding the drill. For the character of work employing the use of sensitive drilling machines and speed lathes, a light chuck similar to the Almond is generally used. This type of chuck is held in the spindle by means of a taper shank, which is either screwed or forced into a corresponding thread or taper in the chuck body. The chuck jaws, operated by a single nut, move in three holes or passages which converge toward the center line of the chuck. Upon any movement of the knurled

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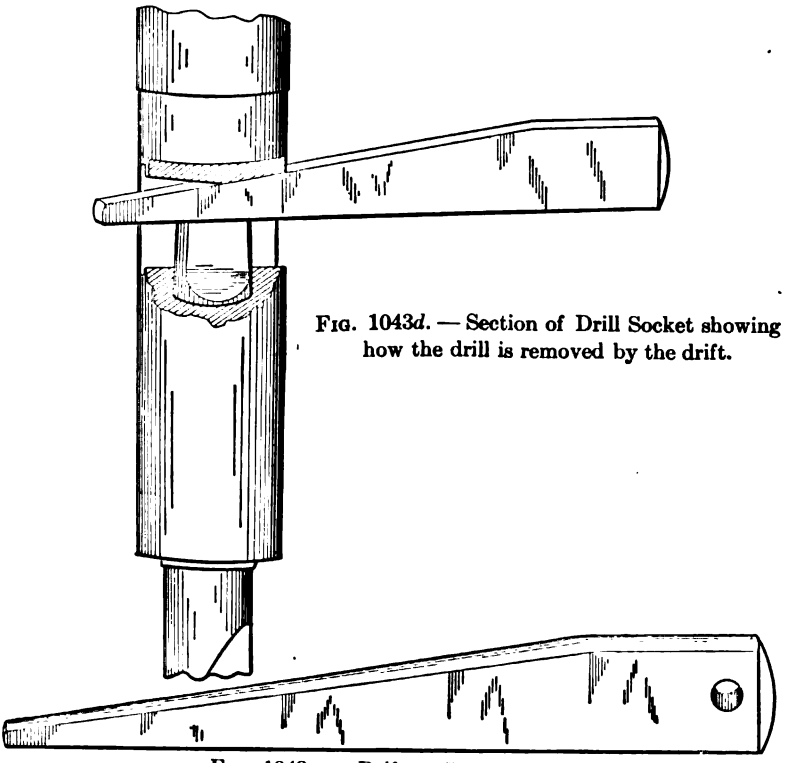

FIG. 1043*d*. — Section of Drill Socket showing how the drill is removed by the drift.

FIG. 1043*e*. — Drift or Center Key.

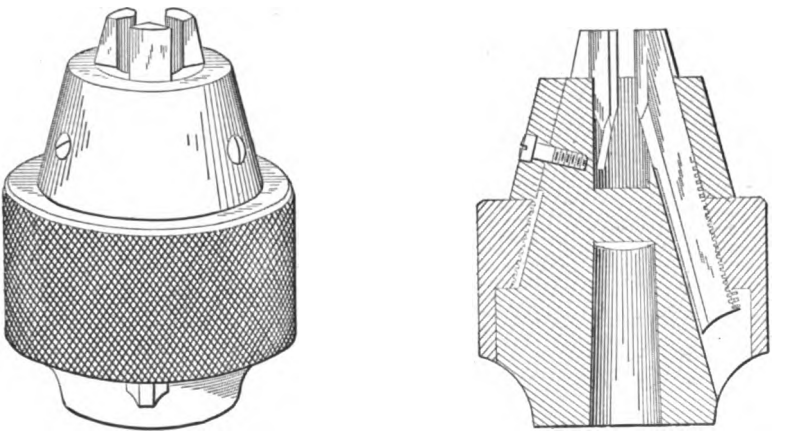

FIG. 1051. — The Almond Drill Chuck.

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collar in which the nut is held, the jaws — so shaped that they are always parallel at that portion which grips the drill — open or close to accommodate the various sizes of drills.

1052. Heavy Drill Chucks. The Pratt and Hartford chucks are excellent examples of the heavier type of drill chucks. The Pratt chuck contains two jaws opposite each other, controlled by a single right and left screw. These jaws move in a slot or guide-way cut across the lower portion of the chuck body. Above the

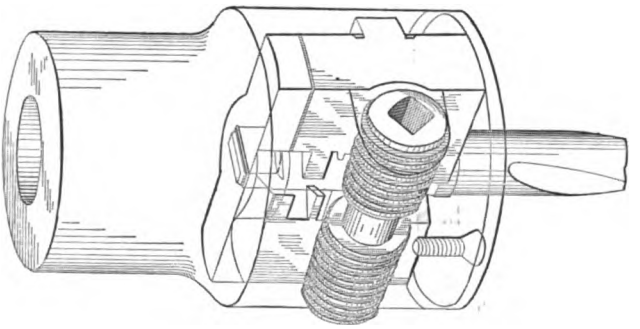

FIG. 1052. — The Pratt Drill Chuck.

jaws, and resting on them, is a plate containing a slot into which the drill tang may be inserted; this prevents the drill from slipping. The faces of the jaws are always parallel and contain grooves to obtain a uniform distribution of the pressure. Below the jaw, screwed to the chuck body, is a plate containing a central hole, whose diameter indicates the maximum capacity of the chuck.

1053. Tapping Chucks. Where a great deal of rapid, accurate tapping is to be done, a machine drill, fitted with a special chuck, is generally used; when such is the case the spindle of the machine is fitted with one of the several automatic reverse tapping chucks now on the market. In one form of these chucks the tap is automatically reversed and backed out after it has run a desired depth; in another form, the tap continues to run forward until a certain resistance is offered, when a reversing gear is thrown into action and the tap backed out. In this second type, this action occurs in either event, whether the tap bottoms or sticks.

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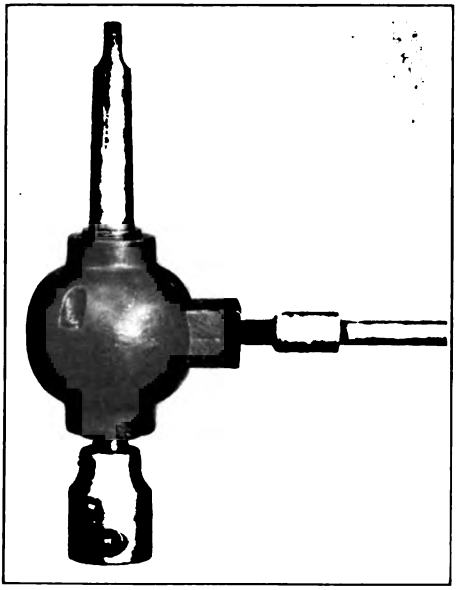

FIG. 1053. — St. Louis Reversing Tapping Chuck.

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CHAPTER XI

GRINDING

1111. Grinding Operations. Hand and Machine. The operations of grinding may be divided into two classes, hand and machine.

Hand grinding defines such abrasive operations as are performed when the object to be ground is held and pressed against the wheel or stone by hand. In the small machine shop, such grinding consists in the removal of irregularities from castings, in the rough rapid reduction of small areas and sometimes in the grinding of shop tools.

Machine grinding may be defined as the production — using abrasive processes — of accurate, plain, cylindrical and conical surfaces by automatic or semi-automatic machines; the accuracy of the surfaces being dependent, rather upon the accuracy of the machine, than upon the skill of the operator. The various classes into which machine grinding is usually divided are: surface grinding, disc grinding, tool and cutter grinding, and cylindrical and conical grinding.

1112. The Dry Grinder and Attachments. A simple form of hand-grinding machine is the common dry grinder. The ordinary type of this machine consists of a column or base supporting the bearings in which revolves a spindle, designed for carrying the driving pulley and two emery wheels, one on each end. Suitable adjustable rests, on which the work is supported during the operation, and a water cup into which it may be dipped when heated, are also provided. Grinders of this type are made in a wide range of sizes, and carry wheels from three inches to three feet in diameter. Dry grinders are sometimes equipped with attachments for truing the wheel, for hand surfacing and for buffing.

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FIG. 1112. — Blount Dry Grinder.

1113. The Disc Grinder. Disc grinders are designed for the production of accurate work by hand, and to obviate the difficulty — that of keeping the surface of an emery wheel true —

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inherent in all emery grinders, the characteristic difference between this and the ordinary dry grinder being the substituting of metal discs for emery wheels. The grinding is effected by means of emery cloth attached to the sides of the discs; these discs, varying

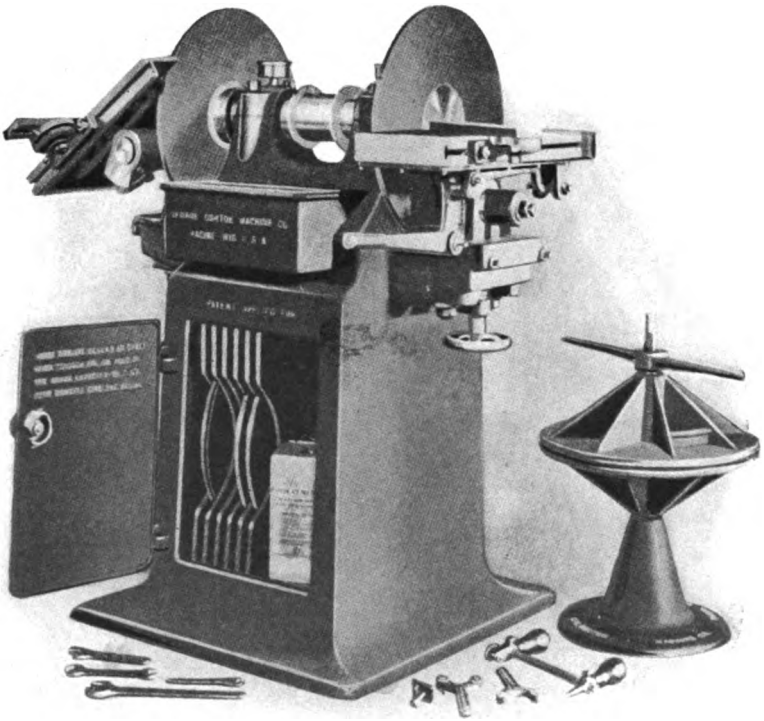

Fig. 1113. — Gorton Universal Flat Surface Disc Grinder.

in thickness from $\frac{1}{2}''$ to $\frac{3}{4}''$, are accurately ground, parallel and true, and in some instances carry on their sides spiral grooves; the object of the grooves being (the emery cloth conforming to the surface) to provide a space into which the particles of emery and metal may be deposited, thus preventing scratching and scoring.

1114. The Wet Grinder. Wet grinders are designed to prevent the heating and the consequent loss of temper which is likely to occur where the tools are ground dry. This type of emery grinder is used almost exclusively for tool grinding, and

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is similar to the dry grinder, with the exception that it is provided with a device for supplying a desired quantity of water to the wheel, and guards for preventing the water from being thrown where it is not wanted. This grinder is never used for rough work, and should be kept true to obtain the best results. Wet grinders are sometimes designed with a universal tool holder for

FIG. 1114. — Whitney Wet or Water Tool Grinder.

holding lathe and planer tools at certain desired angles with the wheel. By consulting the chart furnished with such a machine the holder may be set, and the tool ground with the correct angles of reak and clearance, thus eliminating the personal equation and reducing the product to a standard.

1115. **The Universal Cutter and Reamer Grinder.** The adaptability and extensive use of rotating cutters in milling and kindred operations have led to the development of a specially designed machine, universal within its capacity for the sharpening of all sorts of cutters, reamers, etc. The machine is provided with a full complement of wheels and attachments for performing these operations, and is adapted for doing a limited amount of both internal and external cylindrical and conical grinding.

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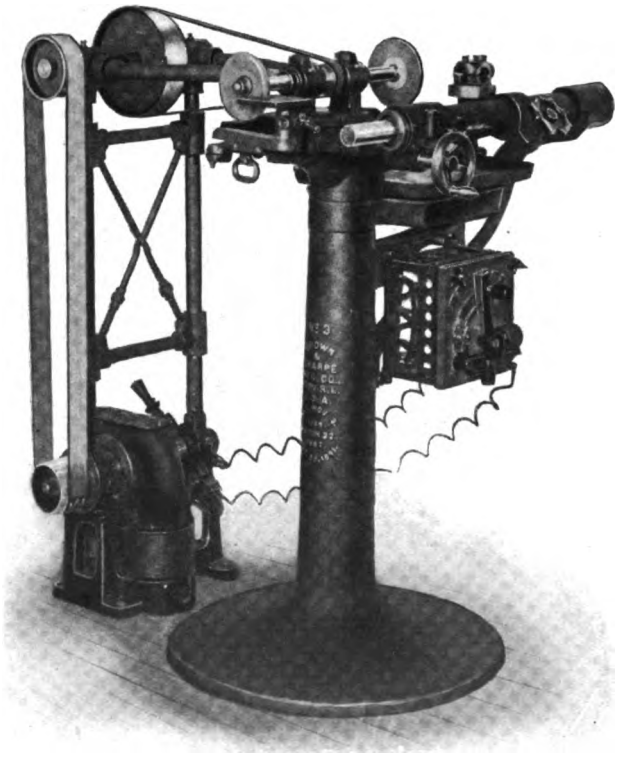

FIG. 1115. — Brown & Sharpe Universal Cutter and Reamer Grinder.

1116. The Drill Grinder. To obviate the necessity of employing a skilled operator who could correctly perform by hand the difficult operation of grinding a drill, the twist drill grinder was invented. In this machine a holder or trough is so adjusted and swung in its relation to the wheel, that when the drill is held in it, the cutting lips are ground at a determined angle and given the proper amount of clearance.

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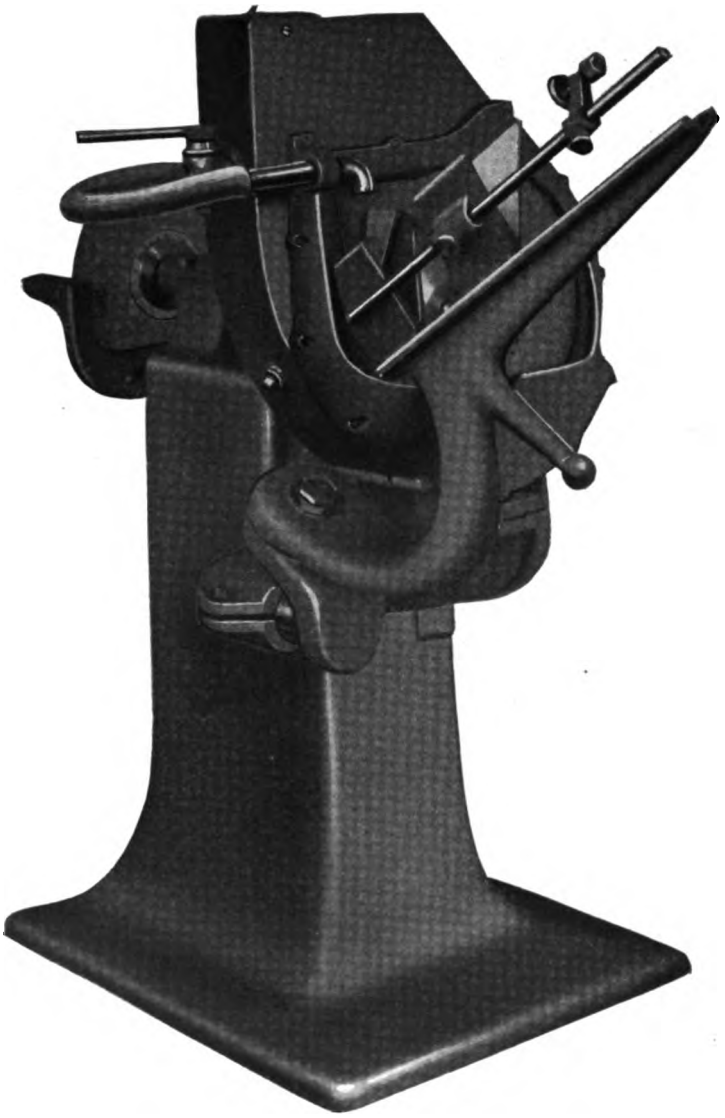

Fig. 1116. — Worcester Inverted Wet Drill Grinder.

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Universal Grinder

1121. Functions and Limitations. The chief function of the universal grinder is the automatic production of accurate cylindrical and conical surfaces. By the use of special attachments furnished with these machines the operator is not only enabled to produce such work and perform a number of internal grinding operations but also accomplish a variety of such intricate grinding operations, as are usually performed on a universal cutter and reamer grinder. Reamers, gear cutters, face, side and end mills, centers, gages and chuck work may be ground and facing operations performed by the use of these attachments.

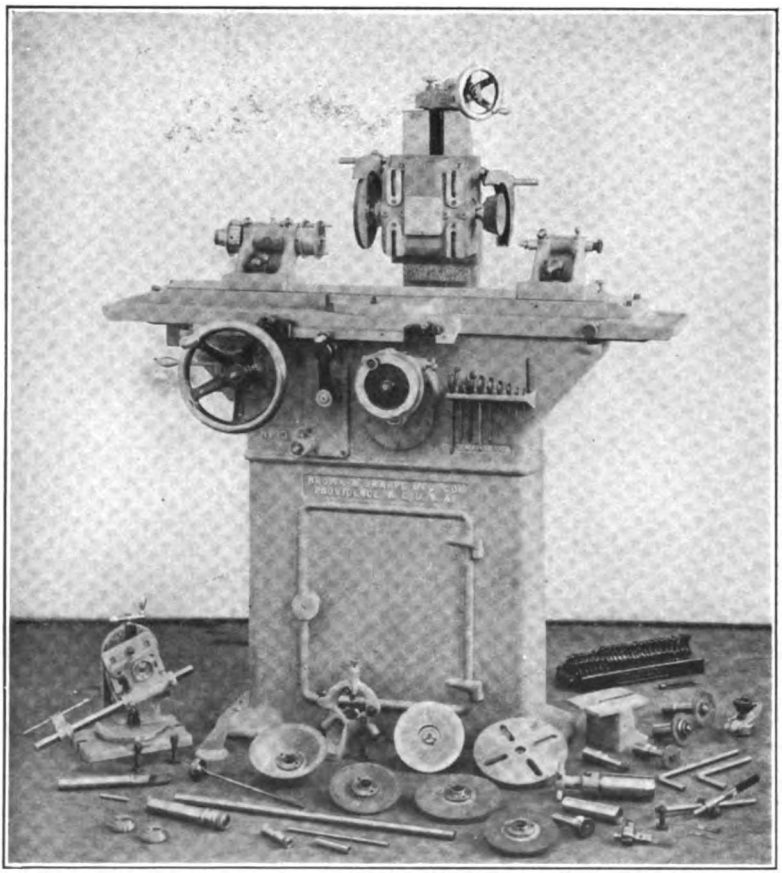

Fig. 1121*a*. — Brown & Sharpe Universal and Tool Grinding Machine (Front).

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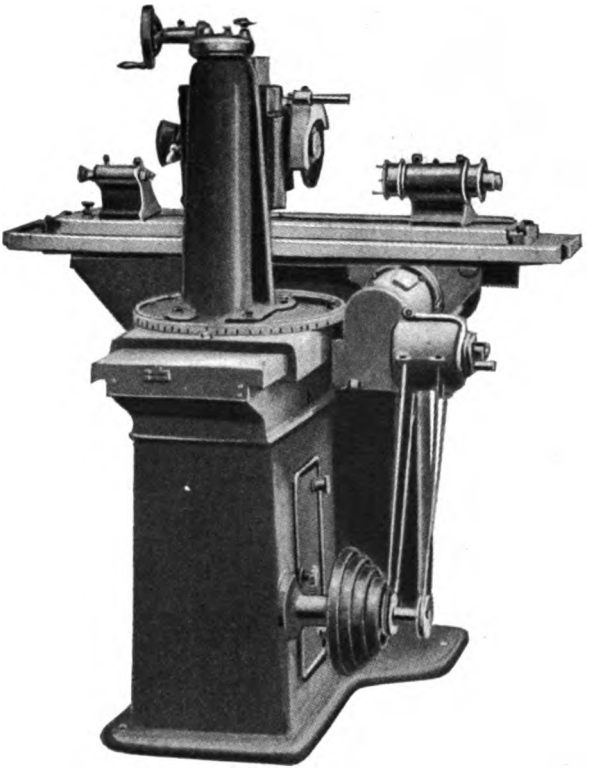

FIG. 1121*b*. — Rear View of Fig. 1121*a*.

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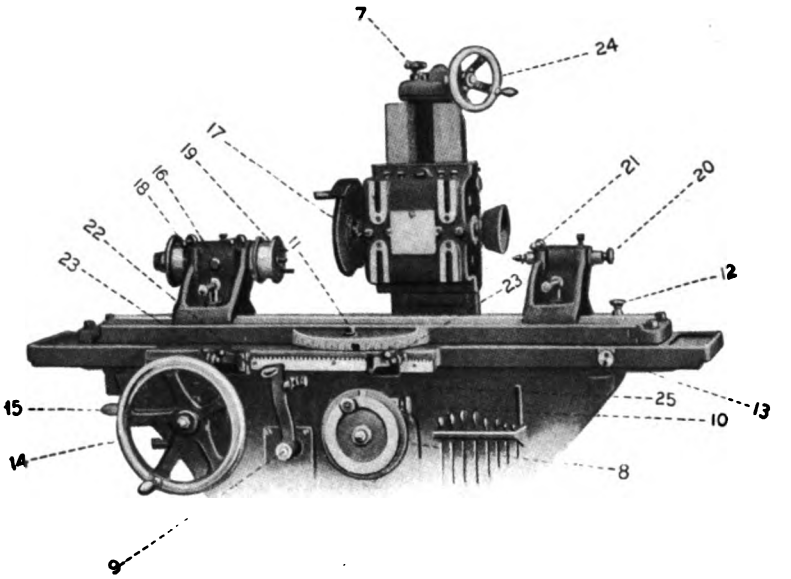

FIG. 1121c. — Brown & Sharpe Machine, Index to Parts Controlling Adjustments and Movements.

INDEX TO PARTS CONTROLLING ADJUSTMENTS AND MOVEMENTS

No. 7. Knob for clamping Elevating Screw Hand Wheel, after setting.
No. 8. Hand Wheel for Cross Feed.
No. 9. Thumb Screw for controlling fine or coarse Cross Feed.
No. 10. Thumb Screw for fine Cross Feed.
No. 11. Bolt for clamping Swivel Table.
No. 12. Spring Knob for engaging fine adjustment of Swivel Table.
No. 13. Thumb Screw for fine adjustment of Swivel Table.
No. 14. Hand Wheel for Table Feed.
No. 15. Lever for controlling Table Feed.
No. 16. Thumb Screw for clamping Head-stock Spindle.
No. 17. Setting Pin.
No. 18. Live Center Pulley.
No. 19. Dead Center Pulley.
No. 20. Adjusting Screw for Foot-stock Spindle.
No. 21. Clamp for Foot-Stock Spindle.
No. 22. Adjustable Table Dogs.
No. 23. Screws for fine adjustment of Table Dogs.
No. 24. Hand Wheel for vertical adjustment of Wheel Slide.
No. 25. Pin for locking Reversing Lever.

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The grinding machine is the most sensitive detector of error in work of any metal working machine in existence. The variation of sparking in grinding an arbor, as often seen, to the minds of many would indicate the work to be very much out of true; the amount of inaccuracy, however, may very often be less than one-fiftieth of one thousandth of an inch. It is possible to take a cut one five-millionth (.000,005″) of an inch in depth. When turned stock is to be finished by grinding, $\frac{1}{32}$″ to .01″ is sufficient stock to allow for the operation.

1122. Description of Parts. The universal grinding machine, formerly termed a grinding lathe, is one with which, within the capacity of the machine, all classes of grinding are accomplished.

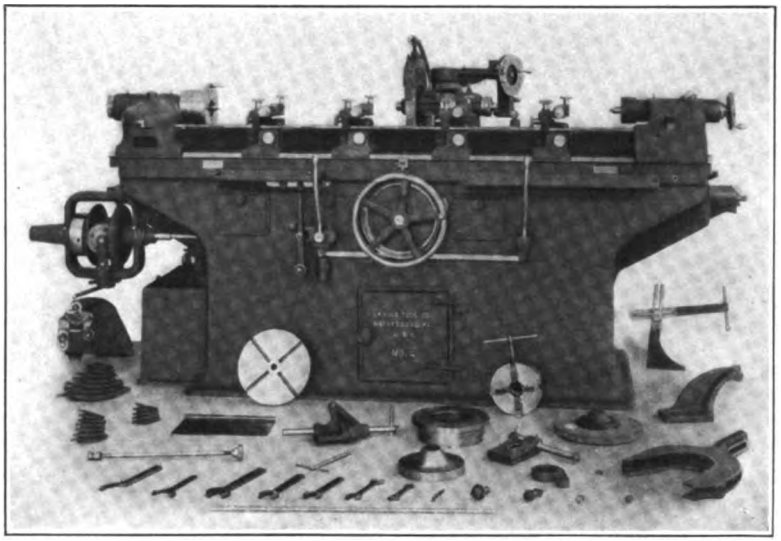

FIG. 1122. — Landis Universal Grinder.

An ordinary form of the universal grinder consists of the following parts: a *column* or *base* enclosing the carriage, operating an automatic reverse mechanism and supporting the wheel carriage and table which carries the head- and tail-stock; a *table* or *bed*, adjustable for taper grinding, which carries the head-stock, the foot-stock and water guard; a *wheel carriage*, sliding in guideways at the back of the column and carrying the slide and wheel; a *swiveled slide*, containing the rotating emery wheel and carrying

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its adjusting mechanism, its water casings and delivery hose; a *swiveling head-stock*, mounted on the table, carrying the spindle, its driving pulley, a center and dead center pulley for rotating the work on the centers; and a *foot-stock*, adjustable on the table, and provided with a lever adjusted spindle and center and a center relieving nut.

In this machine the wheel, revolved from an overhead driver, moves along the rotating work during the grinding operation; in some machines, however, the reverse is the case. Both centers in this class of grinders are *dead centers* because, should the work be revolved by a spindle, it is found that it partakes of any lack of roundness and accuracy inherent in the spindle. A *dead center pulley* provides a means of rotating the work on the centers, thus eliminating any errors that exist because of lack of truth in the spindle. The *spindle* is threaded to receive the chuck and is provided with a pulley by which it may be rotated when desired, and a stop pin to be inserted when operating on dead centers. The foot-stock may be likened to the tail-stock of an engine lathe, and serves the same purpose. Its spindle, carrying the center, is provided with an adjustable spring tension which holds the center in the work with a certain pressure, thus obviating any error that would be due to springing, should the operator jam the center; and providing the means of automatic adjustment for any expansion that may take place in the work.

Ordinarily the wheel is fed to the work by hand by means of a suitably graduated disc and handle, but the advantages of the automatic cross-feed attachment, with which some machines are provided, are obvious. It not only relieves the operator of the necessity of moving the wheel up to the work at the end of each traverse, but automatically stops feeding when the desired diameter is reached; and furthermore it enables one operator to tend to several machines. Contrasting the operation of such a cross-feed with that of the lathe, we find it to be entirely different in construction and operation. A grinder feed must advance the wheel toward the axis of the work a certain amount at the *end of the traverse*, and not constantly as in a lathe. It must also perform this operation a certain predetermined number of times and stop automatically. Such an attachment may be purchased for any of the leading makes of grinders, and on account of the uniformity of its operation it not only maintains a proper condi-

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tion of the wheel, increasing its sizing power, but also, by the stop, prevents the production of work that is too small.

1123. Characteristic Operations. It is important to understand the following operations and adjustments of the universal grinder before starting to work:

1. How to obtain, after its determination, the proper emery-wheel speed; the correct work speed, *i.e.*, the number of revolutions necessary to secure for the particular diameter a perimeter speed of about one hundred feet per minute — this will vary, of course, with the method and character of the work — and the correct rate of wheel traverse; this latter should be faster for finishing cuts, which should be always light, than for roughing cuts; if, however, the face of the wheel is not sufficiently parallel with the surface of the work, a slower traverse should be used, otherwise the work will be ridged.

2. How to start the emery wheel; this is effected by pulling the weighted cord which shifts the belt to the driving pulley. How to start the work; this is effected by means of a shipper-arm attached to a clutch. However, different methods obtain in effecting these operations.

3. The method of adjusting the work in the grinder, not only for the operation of grinding on dead centers, but also for such rough and chuck work as requires the use of the live center.

4. The various adjustments of the foot-stock; how to clamp it in its proper position on the table; the adjustment of the center relieving nut to secure the action of the spring tension; and how to remove the work without altering the adjustment of the foot-stock.

5. The adjustment of the table by means of taper-adjusting and clamping screws, for taper and conical grinding.

6. The adjustment of the water guards on the table, of the delivery nozzle in its relation to the wheel and work, and the proper quantity of water for the operation.

7. The adjustment of the stationary rests and sliding back rests; the clamping of the stationary rest on the table and the sliding rest on the wheel carriage.

8. The automatic traverse mechanism and how to secure, by means of the screw dogs on the traverse wheel, the proper length of traverse.

9. How to instantly start or stop the traverse, either by

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means of the automatic traverse knob, the traverse lever or the shipper arm.

10. Various adjustments of the slide, the wheel spindle, and the feed mechanism; an average feed is about .001″ and feeding should occur only at the end of each traverse.

Caution. Always stop this or any other machine for the taking of measurements, or when it is necessary to leave the machine, be it just for a moment.

Grinding — Hand Abrasive Operations

1131. Hand Grinding. Hand grinding, as has been stated, defines such abrasive processes as are performed when the object to be ground is held and pressed against the wheel or stone by hand. In the small machine shop, such grinding consists in the removal of irregularities from castings, in the rough, rapid reduction of small areas and sometimes in the grinding of shop tools.

1132. Hand Surfacing. The common type of dry grinder is sometimes equipped with an adjustable table through which the emery wheel projects; this table being provided with a movable gage. With such a device, though the surface produced be only approximately flat, hand-surfacing may be done with profit.

1133. Buffing. Buffing may be defined as the operation of obtaining — by means of rapidly revolving cloth or felt discs — a certain grainless finish. The term polishing may refer to the production of any bright finish. Buffing wheels or buffs are made of either felt, or of several discs of cotton cloth sewed together so as to present their edges to the work. By substituting a buffing wheel for one of the emery wheels of a dry grinder, many buffing operations may be successfully performed. Emery cake, a mixture of very fine emery and tallow, is sometimes used on buffing wheels to facilitate the operation.

Grinding — Machine Abrasive Operations

1141. Preparation of the Work. C. H. Norton makes the following remarks in the *American Machinist:*

"Late experience shows it to be practicable to remove one cubic inch of steel per minute from cylindrical work by grinding with suitable wheels. It should not be inferred from this that it is more profitable to leave a large amount of stock on purpose to grind it off with emery wheels; but that in many cases it

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is not practicable to make a quick lathe cut good enough to allow of closer turning on account of spring; and if the lathe cut is not a quick one, at high speed and coarse feed, the grinding wheel will beat it in the simple matter of removing stock, to say nothing of the better surface produced. It is no longer profitable to turn nicely to size in a lathe, when by the use of grinding wheels we can produce better work at much less cost.

"It is also possible to grind many pieces without turning at all more cheaply than to turn them; others require very rude turning only before grinding, while some require closer turning to show economy. For these different classes of work it is necessary to select the wheel to produce the largest saving in time, and best results in quality."

To be specific, we might say that the piece that is subsequently to be ground should leave the lathe from .010″ to .030″ larger than the finished ground diameter.

Good, clean and accurately shaped centers on centered work are essential to all successful grinding operations, and care should be taken to see that both centers are clean, and properly oiled.

1142. Discussion and Classification. Machine grinding, as has been stated, may be divided into several classes; such as surface grinding, disc grinding, tool and cutter grinding, and cylindrical and conical grinding.

It may be stated that the vital difference between the grinder and other machine tools lies in the fact that the cutting tool of steel is replaced by a rapidly rotating wheel made of some abrasive material, such as emery, corundum, alundum, or carborundum. The class of grinding to which most of our remarks will be devoted is cylindrical and conical grinding.

1143. Principles and Advantages Involved in Cylindrical and Conical Grinding. Cylindrical and conical grinding refer to the grinding of solids of revolution, a solid of revolution being a solid generated by the revolution of some plane figure about a line as an axis; thus a right cone is generated by the revolution of a triangle about one of its sides. The fundamental principle underlying the grinding of solids of revolution is the application of thousands of cutting points to the surface of the work, while it is being slowly rotated about its axis. In consequence of each cutting point removing but an exceedingly small particle of metal, the pressure due to the cutting operation is very light.

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Because of this fact, the disturbance of the axes of the work and the wheel is correspondingly small, insuring great accuracy in the work.

It is evident that if a truly cylindrical surface is desired, the grinding wheel must traverse along the surface of the rotating solid in a straight line parallel to its axis of rotation. If the line of motion of the wheel is at an angle to the axis of rotation of the solid, it will be ground conical. An emery wheel having a diameter of 18″ x ¾″ face, when running at its ordinary speed, presents approximately 2,500,000 cutting points to the work in one minute; though each particle is minute, the aggregate amount is comparatively large. Taking into consideration the fact that in modern grinding machines the cutting points pass over from one to four square feet of surface per minute, it is readily seen how these numerous cutting points can remove, as recent practice shows, about one cubic inch of steel per minute from cylindrical work, this being about 17 pounds per hour.

The advantages of machine grinding are: first, the economical production of finished sized work; second, the great accuracy obtainable by this method. The first advantage is to-day the most important one.

1144. Discussion of Speeds, Traverse and Temperature. In the Landis universal grinding machine, No. 1, the emery wheel, which is 10″ in diameter, has five changes of speed from 1529 to 3301 revolutions; while the speed of the work has twelve changes, from 40 to 624 revolutions per minute. The speed at which the wheel rotates varies with the hardness of the work and the amount of stock to be removed at each cut. The traverse of the wheel should be greater for finishing cuts (which should always be light) than for roughing cuts. Wheels should be of such a grade that the dull particles will break away easily during the grinding operation; if the dull particles do not break away they become duller and collect metal, resulting in the glazing of the wheel which causes heating or chattering. A wheel that glazes rapidly is either too hard for the work it is performing, or it is running too fast.

The harder the material to be ground, the softer should be the grade of the grinding wheel; for the harder material, dulling the wheel more rapidly necessitates a faster removal of the dulled particles.

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The speed at which the work rotates may be likened to the feed of the work in a milling machine, or the tool in a lathe; while the cutting points in the grinder wheel may be likened to the cutting edges. In other machines, if the work or tool be fed too fast, the resulting heat draws the temper of the cutting edges, which are rapidly dulled in consequence of the excessive feed; if fed too slowly, the cutter may be said to rub the work instead of taking a distinct chip — this also resulting in a rapid dulling of the cutting edges.

If we rotate the work too fast, when the grinding wheel is running at the proper speed, there will be too much stress upon the cutting points, causing the work to chatter and which, by their breaking away, rapidly change the diameter of the wheel and consequently the diameter of the work. For this reason, too great a surface speed of the work rapidly destroys the sizing power of the wheel.

The wheel will also dull rapidly in case we revolve the work too slowly, because there is not enough stress on the cutting points to break them. In ordinary practice, the peripheral speed of the grinding wheel ranges from 6,000 feet per minute for hard metals to 7,000 feet for soft ones. The average perimeter speed of the work is about 100 feet per minute.

It is especially important that no change in the temperature of the work occur, as a change in temperature produces a resultant change in the axis, rendering it impossible to produce true work. To obviate this difficulty the work is flooded with water.

1145. Trial Settings. The graduations on a universal grinder, those on the table ends, the head-stock, the slide, and elsewhere secure approximate settings only, not because they are inaccurate, but because of changes in temperature and wear in the emery wheel, etc. The necessary trial settings should always be made as carefully as possible, but as soon as the entire surface becomes bright, the feeding should stop, the machine be allowed to operate until the sparking ceases, and then stopped for accurate measurements with the micrometer or gage. If the settings are inaccurate, others should be made and the process repeated until final correct settings are had.

1146. Chattering. Chattering is caused if the grinding wheel is operating at the correct speed, by rotating the work too rapidly. Other common causes are looseness in the wheel spindle, lack of

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truth in the wheel, too wide a wheel face, inherent lack of stiffness in the work, and too hard a wheel. The following remedies are suggested: slender work should be supported by the steady rest; adjustments should be carefully made and tested; the wheel should be trued if not round, replaced if too hard or too wide, although if too wide, it might be thinned down with the diamond; if the work be rotated too rapidly, it should be given a slower speed.

1147. Remarks and Reputable Practice. The following extracts are taken from an article by Mr. Norton which appeared in the *American Machinist:*

"The amount of work produced by grinding has increased with the increase of water, and now it is known that soda water increases the product from any given wheel; later the introduction of oil into the soda water has still further increased the effectiveness of wheels, and made the work of the operator pleasanter, on account of greater neatness. Recently the writer has used a so-called 'drilling compound' and found it excellent when sufficient soda is added to prevent rust.

"All really good wheels will grind in either soda water, soapy water or oil. It is only necessary that they be graded rightly. The popular idea that oil must not be allowed to get near any grinding wheel is erroneous. It would be bad to soak some wheels in oil, or to allow oil to penetrate in spots; but no really good wheel to-day can be injured by flowing liquid oil on to the work or wheel while the wheel is revolving at a sufficient speed to accomplish its work; and some wheels may be soaked in oil indefinitely without the slightest injury.

"Another erroneous impression, not, however, so common, is that emery adheres to ground surfaces, causing cutting of bearings, when used. It would seem clear to reason that should the emery adhere to the steel there could be no grinding, but instead the wheel would be torn away. The fact is that neither the microscope nor chemical laboratory reveals an atom of carbon in any form adhering to the steel.

"There still remain a few who suppose that copper, Babbitt, lead, and soft rubber cannot be ground with emery and corundum wheels because the material adheres to the cutting wheel; when, the fact is, there is no substance of which the writer has any knowledge that cannot be ground successfully with a wheel suitably constructed for each case."

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1148. Order of Operations for Cylindrical and Conical Grinding. Observe the following order of procedure when operating the universal grinder:

1. *Adjust the work.* Attach a special grinder dog to one end of the work, put a drop of oil in the center in each end, and place between the clean centers of the grinder, noting that no end play exists, *i.e.*, that the spring tension is in operation. When taper grinding, the table must be set by means of the adjusting screw. A setting is effected by traversing the emery wheel back and forth and noting the difference between the wheel and the work in the extreme position. In most instances these should be equal; in other words, the line of the wheel traverse should be parallel with the rough surface of the work.

2. *Adjust the emery wheel and traverse carriage.* The emery wheel is brought into its proper relation with the work, and the screw dogs adjusted on the traverse wheel to give the desired length of the traverse; this latter adjustment may be effected by moving the traverse carriage back and forth with the traverse wheel by hand. Special precaution must be taken to see that the wheel does not collide with the dog or any projection on the work or chuck.

3. *Determine the speeds and traverse.* Calculate the speeds and consult the table, Sec. 428, then adjust the belts to obtain them.

4. *Pull over by hand.* With all adjustments made and the wheel and work in position, pull over by hand, and traverse the carriage to avoid breakage and to ascertain the accuracy of the adjustments.

5. *Adjust the water guards.* Adjust the water guards and turn on the water.

6. *Start the grinder.* With the work revolving and the running wheel at one end of its traverse, bring it slowly towards the work until it begins to cut.

7. *Throw in the automatic traverse.* By means of the automatic traverse knob and lever, throw in the automatic traverse, feeding the wheel only at the end of each cut. The work should be carefully watched to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time.

8. *Take measurements.* As soon as the entire surface has

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become bright, stop feeding and allow the machine to operate until the wheel ceases to spark. Stop the machine and measure the diameter at each end with the micrometer calipers or gage; if the adjustment is incorrect, the table is readjusted and the operation is repeated; a few trials will probably be necessary before the exact adjustment is obtained.

Note. To avoid the production of work that is too small it is necessary in sizing to use the utmost care both in grinding and in the taking of measurements.

1149. Lapping. Lapping is an abrasive process of refinement and bears the same relation to the finishing of ground work that scraping does to the finishing of planed work. A lap is composed of some soft metal such as lead, brass or cast iron, in which are imbedded the grains of the abrading material; in general, only the very finest numbers of flour emery are used. Where necessary that either the lap or the work be rotated at a high speed during the lapping process, this may be done in a speed lathe. It is essential, in order to secure a successful operation, that plenty of oil be supplied to the lap.

Plane surfaces may be lapped in the following manner: the face of the lap, which is usually cast iron, is coated with oil and emery; the work is then rubbed over it, care being taken to change the direction of the rubbing frequently in order to prevent crowning.

Abrasives and Abrasive Wheels

1151. Carborundum — Scale of Hardness. Carborundum (carbide of silicon) SiC, is an artificial abrasive and is manufactured in an electric furnace. In the following scale of minerals taken to represent the 10 degrees of hardness, talc ranking 1 and the diamond 10, carborundum will be found between the numbers 9 and 10. (1) Talc (easily scratched with the finger nail); (2) Gypsum; (3) Calcite; (4) Fluorite; (5) Barite; (6) Feldspar; (7) Quartz; (8) Topaz; (9) Corundum or Sapphire (a form of crystallized corundum); (10) Diamond (the hardest substance known).

1152. Alundum. Alundum, a recently developed abrasive, is produced, like carborundum, in an electric furnace at an extremely high temperature. Alundum is claimed by the manufacturers, the Norton Emery Wheel Co., to be the hardest, sharpest, and most durable abrasive material known. The raw material, Beauxite, an amorphous hydrate of aluminum, is transformed

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at a temperature estimated between 6000 and 7000 degrees Fahrenheit, into alundum, a material resembling in chemical composition the purest natural corundum. In the scale of hardness, where the diamond is 10, alundum has been found by trial to exceed 9½.

1153. **Corundum.** Corundum is pure alumina or oxide of aluminum, Al_2O_3. It is a natural mineral, crystalline in structure, and in the scale ranks next to the diamond in hardness.

1154. **Emery.** Emery is a compound of corundum and protoxide of iron. Its hardness is about one degree lower than corundum, while the presence of iron renders the grains slightly tougher and less brittle. The most important emery mines are to be found in the northeastern portion of the United States.

1155. **Grindstones.** Grindstones are natural sandstones of a suitable texture for grinding. The cutting material is quartz sand, oxide of silica, SiO_2, the grains of which are bound together by a natural calcareous or silicate bond. The stone is quarried and turned into discs; these latter are the grindstones of commerce.

1156. **Abrasive Wheels and Wheel Speeds.** Commercial abrasive wheels are manufactured from carborundum, alundum, corundum and emery by combining the cleaned and sorted grains of the cutting material with a suitable matrix or bond. The wheels are pressed into shape and are hardened by a process of drying or vitrification as the nature of the bond requires. It is essential in all abrasive wheels that the bond be of such a nature, whether natural or artificial, that it be soft enough to release the grains after their projecting corners have been worn; hard enough to retain the grains until these corners have done their work; and of such strength that the wheel will be capable of resisting the centrifugal force due to the speed at which such wheels must be run to secure the greatest efficiency.

The table of abrasive wheel speeds (Fig. 1156) gives the number of revolutions per minute for specified diameters of wheels, to cause them to run at the respective periphery rates of 4000, 5000, 6000 and 6500 feet per minute. A rate of 5000 feet is usually employed in ordinary work, but in special cases and where safety collars are used, it is sometimes desirable to run them at a higher or lower rate according to the requirements. The stress on the wheel at 4000 feet per minute is 43 pounds per square inch; at 5000 feet, 75 pounds; and at 6000 feet, 108

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pounds. Wheels that are to be run wet, like tool-grinder wheels, are usually run at the lowest speed of 4000 feet per minute, as that is about as fast a speed as water can be kept on the surface of the wheel. Wheels with holes $\frac{1}{3}$ to $\frac{1}{2}$ their diameter are much weaker than solid wheels of the same size, and should not be run faster than 4000 feet. Tub or cup wheels, if not protected in any manner, should be run between 3000 and 4000 feet per minute, while ring wheels in chucks may be run from 5000 to 6000 feet per minute.

TABLE OF ABRASIVE WHEEL SPEEDS

	SLOW FOR WET AND CUP WHEELS	ORDINARY FOR GENERAL SHOP PRACTICE	MEDIUM FOR WHEELS WITH SAFETY COLLAR	MAXIMUM FOR WHEELS WITH SAFETY COLLAR
Diameter Wheel	Rev. per minute for surface speed of 4,000 ft.	Rev. per minute for surface speed of 5,000 ft.	Rev. per minute for surface speed of 6,000 ft.	Rev. per minute for surface speed of 6,500 ft.
1 inch	15,279	19,099	22,918	24,000
2 "	7,639	9,549	11,459	13,000
3 "	5,093	6,366	7,639	8,670
4 "	3,820	4,775	5,730	6,240
5 "	3,056	3,820	4,584	5,200
6 "	2,546	3,183	3,820	4,333
7 "	2,183	2,728	3,274	3,500
8 "	1,910	2,387	2,865	3,100
10 "	1,528	1,910	2,292	2,500
12 "	1,273	1,592	1,910	2,050
14 "	1,091	1,364	1,637	1,775
16 "	955	1,194	1,432	1,550
18 "	849	1,061	1,273	1,375
20 "	764	955	1,146	1,250
22 "	694	868	1,042	1,125
24 "	637	796	955	1,035
26 "	586	733	879	950
28 "	546	683	819	886
30 "	509	637	764	825
32 "	477	596	716	780
34 "	449	561	674	728
36 "	424	531	637	700
38 "	402	503	603	655
40 "	382	478	573	624
42 "	364	455	546	600
44 "	347	434	521	565
46 "	332	415	498	541
48 "	318	397	477	500
50 "	306	383	459	496
52 "	294	369	441	478
54 "	283	354	425	461
56 "	273	341	410	443
58 "	264	330	396	428
60 "	255	319	383	414

FIG. 1156.

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1157. Number of Grains and Character of Surface Cut by Them. The number or *grain* of a wheel refers to the size of the grains of which it is made. The grains are divided and numbered as follows, the numbers indicating the threads per lineal inch in the sieves through which they pass: 6, 8, 10, 12, 14, 16, 20, 24, 30, 36, 40, 46, 50, 60, 70, 80, 90, 100, 120, 150, 180 and 220.

The degree of smoothness of the surface which these numbers leave may be roughly compared to that left by files, as follows:

8 and 10 represent the cut of a wood rasp.
16 and 20 represent the cut of a coarse rough file.
24 and 30 represent the cut of an ordinary rough file.
36 and 40 represent the cut of a bastard file.
46 and 60 represent the cut of a second cut file.
70 and 80 represent the cut of a smooth file.
90 and 100 represent the cut of a superfine file.
120 and finer represent the cut of a dead smooth file.

1158. Grade or Hardness. The *grade* of an abrasive wheel refers to its hardness, that is, the resistance of the particles to the pressure exerted in the act of grinding. A wheel whose particles are easily broken away from it is termed soft, while one from which the particles are not easily broken is hard.

The Norton Emery Wheel Co. uses 26 grade marks, the Carborundum Co. 19, while the Safety Emery Wheel Co. uses 40. The following table (Fig. 1158) is a comparison between the grade designations of the Norton Emery Wheel Co. and the Carborundum Co. Intermediate letters between the grade designations indicate relative degrees of hardness between them. The Norton Emery Wheel Co. manufacturing four degrees of each designation, while the Carborundum Co. manufactures but three.

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Norton Emery Wheel Co.	Grade Designation	Carborundum Co.
	Extremely or	
A	Very Soft	V
B		U
C		T
D		
E	Soft	S
F		R
G		Q
H		
I	Medium Soft	P
J		O
K		N
L		
M	Medium	M
N		L
O		K
P		
Q	Medium Hard	J
R		I
S		H
T		
U	Hard	G
V		F
W		E
X		
Y	Extremely or	D
Z	Very Hard	

FIG. 1158.

The Safety Emery Wheel Co.'s grade list is an arbitrary one with the following designations:

C. Extra Soft	H. Very Soft
A. Soft	M. Medium Soft
P. Medium	I. Medium Hard
O. Hard	N. Very Hard
E. Extra Hard	D. Special Extra Hard

Intermediate figures between those designated as soft, medium soft, etc., indicate so many degrees harder or softer, *e.g.*, A$\frac{1}{2}$ is

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one degree harder than soft. A¾ is three degrees harder than soft or one degree softer than medium soft.

1159. Favorite Numbers and Grades of Abrasive Wheels. In Fig. 1159*a*, a table for the selection of grades, will be found a comparison of the grading used by the Norton Emery Wheel Co. and that of the Carborundum Co. Fig. 1159*b* is the grading list used by the Safety Emery Wheel Co.

Class of Work	Norton Emery Wheel		Carborundum Co.	
	Number Usually Furnished	Grade Usually Furnished	Number Usually Furnished	Grade Usually Furnished
Large Cast Iron and Steel Castings	16 to 20	Q to R	16 to 24	G to H
Small Cast Iron and Steel Castings	20 to 30	P to Q	20 to 30	G to H
Large Malleable Iron Castings	16 to 20	Q to R	16 to 24	G to H
Small Malleable Iron Castings	20 to 30	P to Q	20 to 30	H to I
Chilled Iron Castings	16 to 20	Q to R	16 to 24	H
Wrought Iron	16 to 30	P to Q	16 to 24	F to H
Brass Castings	16 to 30	O to P	20 to 36	H to I
Bronze Castings	16 to 30	P to Q	20 to 30	I
Rough Work in General	16 to 30	P to Q	20 to 30	H
General Machine Shop Use	30 to 46	O to P	24 to 36	G to J
Lathe and Planer Tools	30 to 46	N to O	30 to 36	I to J
Small Tools	36 to 100	N to P	50 to 80	I to J
Wood-working Tools	36 to 60	M to N	40 to 60	L to M
Twist Drills (Hand Grinding)	36 to 60	M to N	60	I to J
Twist Drills (Special Machines)	46 to 60	K to M	50	L to O
Reamers, Taps, Milling Cutters, etc. (Hand Grind)	46 to 100	N to P	50 to 80	K to N
Reamers, Taps, Milling Cutters, etc. (Spec. Mach.)	46 to 60	H to K	50 to 60	L to M
Edging and Jointing Agricultural Implements	16 to 30	Q to R	141 to 24	G to I
Grinding Plow Points	16 to 30	P to Q	20 to 24	H
Surfacing Plow Bodies	20 to 30	N to O	16 to 20	G
Stove Mounting	20 to 36	P to Q	24 to 30	G
Finishing Edges of Stoves	30 to 46	O to P	24 to 30	G
Drop Forgings	20 to 30	P to Q	24 to 36	G to I
Gumming and Sharpening Saws	36 to 60	M to N	403—603	J to L
Planing Mill and Paper Cutting Knives	30 to 46	J to K	202—60 to 80	M to R
Car Wheel Grinding	20 to 30	O to P	16 to 24	H

Fig. 1159*a*.

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THE GRADING USED BY THE SAFETY EMERY WHEEL CO. OF SPRINGFIELD, OHIO

Kind of Work	Number Usually Furnished	Grade
COARSE GRINDING		
Stove castings	20 to 30	I ¾ to O ½
Agricultural castings (malleable and gray iron)	16 to 20	I ¾ to O ½
Small malleable castings	24 to 36	O ½ to N
Drop forging fins	20 to 30	O to N
Scale from soft steel forging	20 to 30	O to O ½
Rough brass castings	20 to 24	I ¾ to O ½
Roughing out large machine-shop tools	24 to 30	I to I ¾
Rough surfacing on wrought iron	16 to 24	I ½ to O
Surfacing soft steel (coarse)	20 to 30	I ½ to O ½
Surfacing cast iron (coarse)	16 to 30	I to O
Surfacing chilled iron (coarse)	20 to 30	I ½ to O ½
Edging shovels	20 to 30	O to O ¾
Steel plow jointing	20 to 24	I ½ to O
Jointing and edging agricultural implements	20 to 30	I to I ¾
Thin edges of hollow-ware	20 to 30	N to N ½
Chilled car-wheel grinding	16 to 20	I ½ to I ¾
Cast-iron car-wheel grinding	16 to 24	I ½ to I ¾
Grinding car-wheel tires (steel)	20 to 30	I ½ to I ¾
Edges of wrought-iron butts and hinges	20 to 30	O to O ½
Rough grinding on malleable car couplings	14 to 20	O ½ to N
Grinding edges of cast-iron radiators	20	O to O ½
Grinding wood pulp	20	N
Rough surfacing on sad irons	20 to 30	I ½ to O
Grinding ends of iron or steel rods	20 to 30	O ½ to E
Jointing wrought-iron bridge work	16 to 20	O ½ to O ¾
Surfacing cast-iron mold boards	20 to 36	I ½ to O
Bronze casting	20 to 30	O to O ½
Rough machine-shop use	20 to 30	I ½ to O ½
Edging sheet steel	30 to 36	I ¾ to O ½
Wrought-iron wagon work	20 to 36	O ½ to O ¾
Grinding ends of carriage axles	20 to 36	O to O ¾
Internal grinding (roughing out)	24 to 46	I ½ to O ½
Surface work on dies	20 to 46	M ½ to I
Surface work on carriage axles	20 to 36	I ¾ to O
Safe work	16 to 20	P ½ to O
Edging sad irons	20	O to O ½
MEDIUM GRINDING AND COARSE TOOL WORK		
Saddlery hardware castings (malleable)	24 to 36	N or E

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GRADING USED BY SAFETY EMERY WHEEL CO. (*continued*).

Kind of Work	Number Usually Furnished	Grade
MEDIUM GRINDING AND COARSE TOOL WORK — CONTINUED		
Surface brass (coarse)	30 to 36	P to P ½
Surfacing tempered steel (coarse)	36 to 46	M to P
Grinding cast-steel hammers	30 to 36	I ½ to I ¾
Jointings edges of sheet-iron or steel	20 to 36	I ½ to O ½
Surfacing chilled-iron plows	20 to 30	I ½ to O ½
Stove mounting	24 to 36	O ½ to N
Polishing edges of stoves	36 to 46	O to O ½
Sharpening lawn mowers	36 to 60	P to I ½
Pointing and sharpening guards	24 to 36	O to O ½
Sharpening mower and reaper knives	46 to 60	I to I ½
Water tool grinding	30 to 46	P to I
Twist drill grinding	46 to 60	A ½ to P
General machine-shop use	24 to 36	I to I ½
Shaping Mushet steel tools	30 to 36	P to I
Sharpening large machine-shop tools	24 to 36	P to I
Grinding inside of cast-iron hollow-ware	30 to 46	P ½ to I ½
Grinding inside of stamped hollow-ware	36 to 46	P ¾
Finishing the heads of machine screws and bolts	36 to 46	P ½ to I
Gumming and sharpening saws	46 to 60	A ½ to M ½
Planing-mill tools, molding cutters, etc	46 to 60	M
Planing-mill and paper-cutting knives	36 to 60	A to A ½
Lathe and planer tools	30 to 46	P to I
Edging files	30 to 60	I to I ¾
Ends of wagon springs	30 to 46	O to O ½
Surfacing faces of pulleys	30 to 36	I to I ½
Grinding out boiler holes in stove tops and centers	30 to 46	O ¾ to N ½
Small malleable or gray-iron castings	24 to 36	I ¾ to O
Bottoms and edges of iron shoe lasts	30	I ½ to O
Grinding shear knives	30 to 36	A ½ to M
Surfacing sides of circular saws	36 to 60	A ½ to M
Rim bands on carriage hubs	36 to 46	I to O
Brass car boxes	30 to 36	I ½ to O ½
Grinding ends of spiral springs	46 to 60	I ¾ to O ½
Leveling off rivet heads	30 to 36	I ½ to O
FINE GRINDING AND TOOL FINISHING		
Universal grinding machine	60 to 100	A ½ to M
Sharpening small machine-shop tools	60 to 80	M to P ½

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GRADING USED BY SAFETY EMERY WHEEL CO. (*continued*).

Kind of Work	Number Usually Furnished	Grade
FINE GRINDING AND TOOL FINISHING — CONTINUED		
Sharpening reamers and taps	60 to 100	A ¾ to M ½
Sharpening milling cutters	60 to 100	A ¾ to M ½
Grinding chilled rolls	36 to 46	A ½ to M ½
Finishing chilled rolls	60 to 100	A ½ to M
Grinding pearl	46 to 100	A ¾
Grinding leather splitting knives	90	A ½
Brass finishing	60 to 100	M
Dental and surgical instruments	46 to 100	M to P ½
Grinding and concaving razors	70 to 100	A ½ to M
Grinding shoe knives	70 to 90	P ½ to I
Fine hardened steel tools	80 to 120	A ½ to M ½
German silver	80 to 120	M to P
Shoe cutting dies	60 to 80	P to I
Ends of steel wire	70 to 90	P ½ to I ½
Internal grinding (finishing)	60 to 100	M to M ½
Grinding lathe centers	60 to 80	M

FIG. 1159*b*.

To get a fine finish use the finer numbers and soft grades. For fast work the coarse numbers and hard grades.

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CHAPTER XII

PLANING

Planing Machines

1211. Classes of Planing Machines. There are three distinct classes of planing machines in common use, viz.: the shaper for light work; the slotter for finishing flat or curved surfaces, at right angles to some other surface of the work, and the planer for heavy work. There are several varieties of each of these classes, the design of each class varying according to the ideas of the manufacturer, and the work for which the machine is intended.

Shapers are usually crank or gear driven, while planers are spur or spiral-geared, the adjectives having reference to the method of driving the platen.

The Shaper

1221. Function and Limitations. The function of the shaper, like that of the planer, is to produce flat surfaces. It is designed for light work, and work of such character as may be held in a vise, with which it is usually equipped. In contrast with the planer, the tool moves over the work instead of the work under the tool. In the planer the tool is fed sidewise during the return stroke of the work, while in the shaper the work feeds sidewise during the return stroke of the tool. In this machine the head is fastened to one end of a reciprocating ram, which causes the tool to be moved back and forth horizontally over the surface of the work. The carriage, to which the vise and work are fastened, is so arranged as to move sidewise a distance equal to the width of the cut, while the tool is performing the return stroke.

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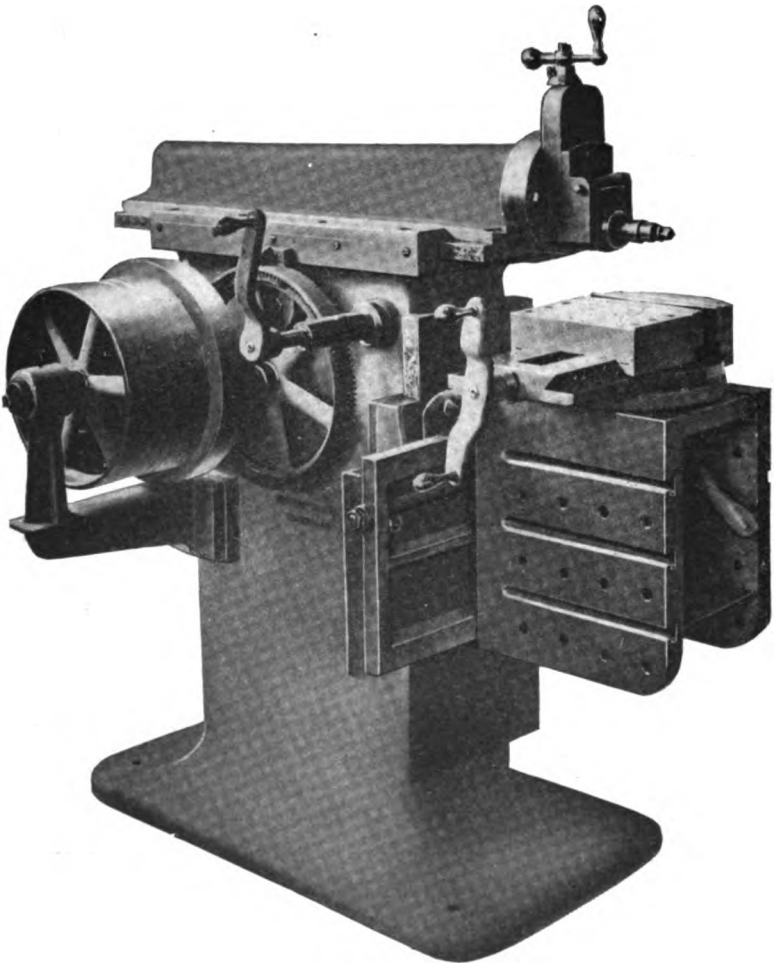

FIG. 1221. — Hendey Geared Shaper.

1222. Description. A standard type of the modern crank shaper consists of a *body* or *column* which supports the driving mechanism, the vise and various stationary and movable parts of the machine; a longitudinally movable *ram*, at the end of which is fastened the *head*, *slide*, *tool-box* and *tool-post*; the column

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also supports the movable *table* to which the *vise* or work is fastened. The ram slides in flat or dove-tailed bearings formed on the top of the column; at its front end it carries the *shaper-head* and *slide* which gives the down feed; this head is always so arranged that it can be adjusted in such a manner as to make any angle with the top surface of the table; it is provided with

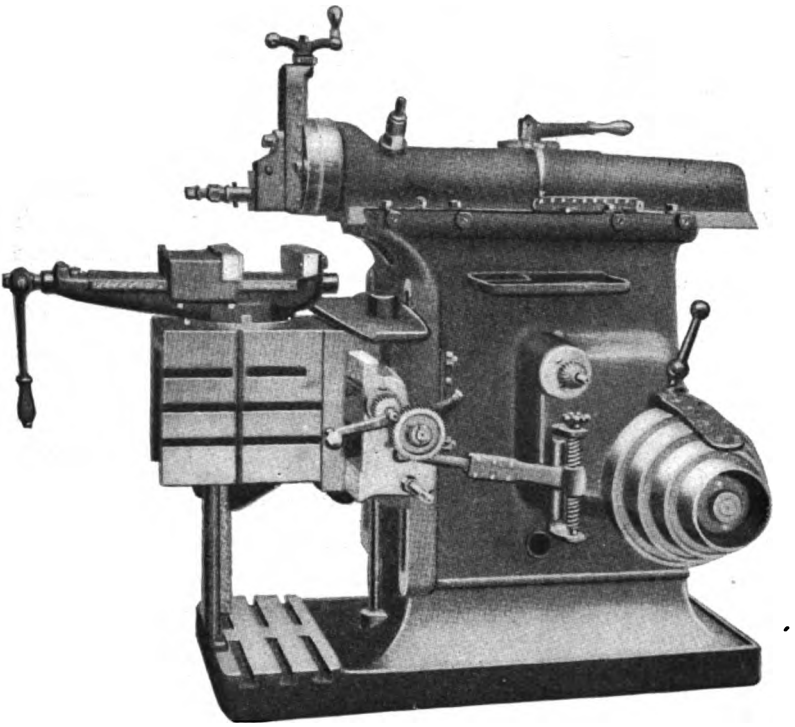

FIG. 1222. — Gould & Eberhardt High-duty Crank Shaper.

suitable locking arrangements. The driving mechanism, by means of which the ram is moved to and fro over the work, is operated by a *cone pulley* through *back gears*, a *crank* and *slotted lever*. The length of the stroke and the position of the ram are adjustable with reference to the work. The table is fastened by bolts to a *saddle* which is gibbed to a *cross-rail* and can be moved along it in either direction, automatically or by hand. The cross-rail, which is attached to the face of the column, may be raised or lowered by means of *screw* and *miter gears*, or clamped to the

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column at any desired height. The table which carries the movable vise is T-slotted, so that large work may be bolted to it. The driving mechanism, enclosed in the column, consists of a *forked block* clamped in a slot in the ram by means of a *handle;* a heavy *slotted lever* is fastened at its lower end to the column, its upper end engaging the forked block. This lever is moved back and forth by means of a *crank-pin* which is carried on the large *gear;* this gear is driven, either by a *pinion* keyed on the same shaft with the cone pulley, or through back gears. As this gear revolves, the crank-pin which carries the block sliding in the lever causes the lever to move back and forth. It is obvious that if we alter the distance from the center of the crank-pin to the center of the gear carrying it, we produce a corresponding change in the stroke of the ram. This is accomplished by having the crank-pin attached to a *quadrant* which can be rotated about a center near the rim of the gear; the quadrant is moved by means of a *rack and pinion;* this pinion is so arranged that it may be operated by hand; when the quadrant is in the desired position it may be clamped there.

1223. Characteristic Operations. It is important to understand the following operations and adjustments of the shaper before starting to work:

1. The correct method of setting the tool, and the adjustment of the tool-box so as to give the necessary relief to the tool on the return stroke.

2. The quick return motion by means of which the movement of the ram is controlled.

3. The adjustment of the back gears to secure the proper cutting speed.

4. The device for regulating the length of the stroke.

5. The device for regulating the position of the stroke.

6. The method of raising or lowering the cross-rail and the movement of the table.

7. The method of adjusting the automatic feed mechanism; how to obtain a desired width of cut.

8. The method of reversing the direction of the feed and how to throw it into or out of action.

9. The method of adjusting so as to make the feeding take place during the return stroke.

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Slotters and Key-way Cutters

1231. Description of Slotting Machines. The slotting machine is a modification of the shaper, and might in fact be termed a vertical one, as the action of the ram is vertical. A common

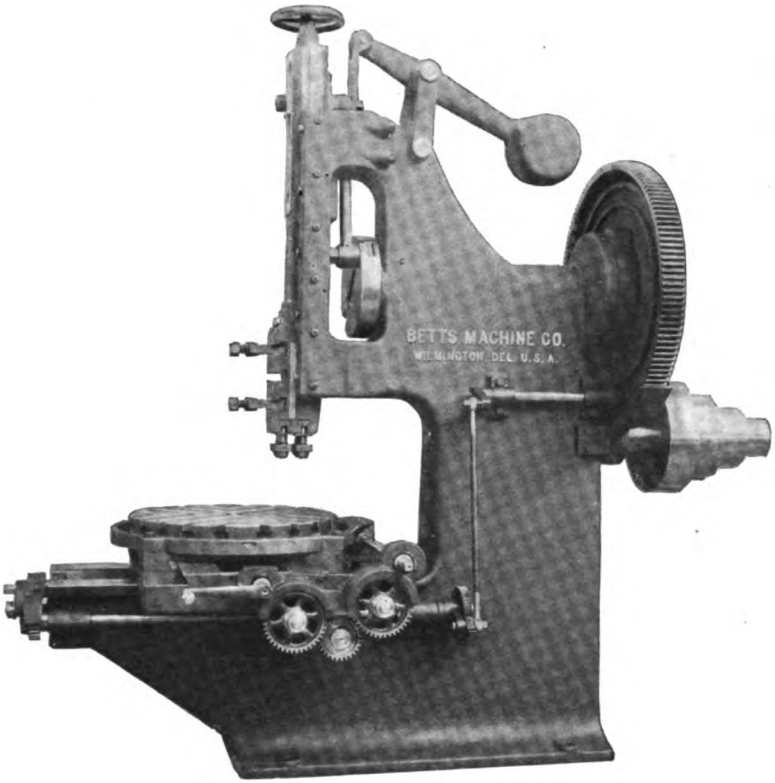

Fig. 1231. — Betts Slotting Machine.

type of slotting machine consists of the following essential details: A rigid frame carrying the ram and its driving mechanism, the carriage and platen, with its automatic feed mechanism; a vertical ram, situated directly above the platen, carries the tool; a circular platen, mounted on a carriage similar to a lathe carriage, is provided with rotary, automatic, longitudinal and cross feeds.

Power is transmitted through a cone pulley and back gears to a crank on the driving shaft, situated back of the ram. The

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rotary motion of the crank is transformed into a reciprocating motion of the ram through adjustable crank and wrist pins and a connecting rod; the ram is counterbalanced and provided with both vertical and horizontal tool clamps.

1232. Slotter Tools. Slotter tools that are used with their shanks in a vertical position are essentially different in shape from either the ordinary planer or shaper tools in that the cutting edge is formed at the end of the bar. They resemble to some extent a parting tool, with the exception that the end face turns the chip. See Sec. 455.

1233. Key-way Cutters. A key-way cutter may be defined as a vertical draw-cut shaper, the *draw-cut shaper* being one designed to cut on what would be the return stroke of the ordinary shaper. As the name implies, this form of slotter is designed primarily for the cutting of key-ways in the hubs of pulleys, gears and similar work.

The Planer

1241. Function and Limitations. The function of the planer is to produce a flat surface; this is accomplished by fastening the work to a movable platen which is made to reciprocate horizontally beneath the tool, the latter being moved after each forward

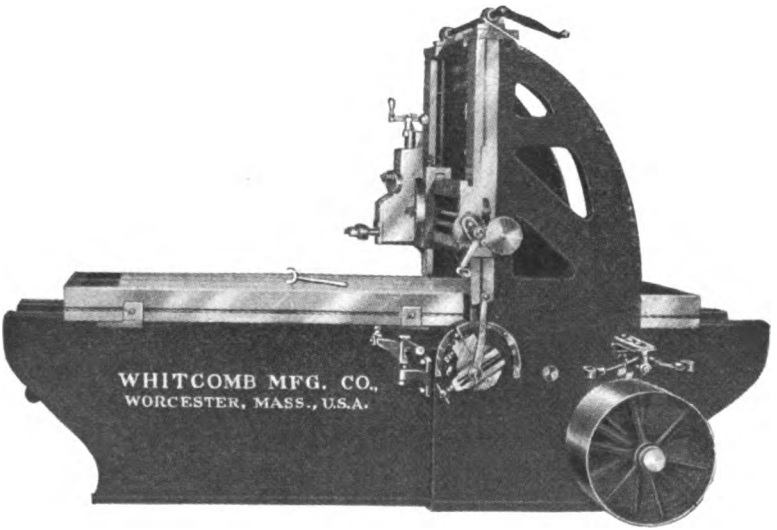

Fig. 1241*a*. — Whitcomb 26″ Belt Drive, Belt-driven Planer.

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stroke of the platen a distance equal to the width of the cut. The tool is fed across the work at right angles to the line of motion of the platen or table. Planers are designed for heavy work, and are generally made to run at a fixed rate of speed — about 24 feet per minute on the cutting stroke; the return stroke is, for obvious reasons, so arranged as to occupy less time than the cutting stroke. That the high-speed tool steels may be used

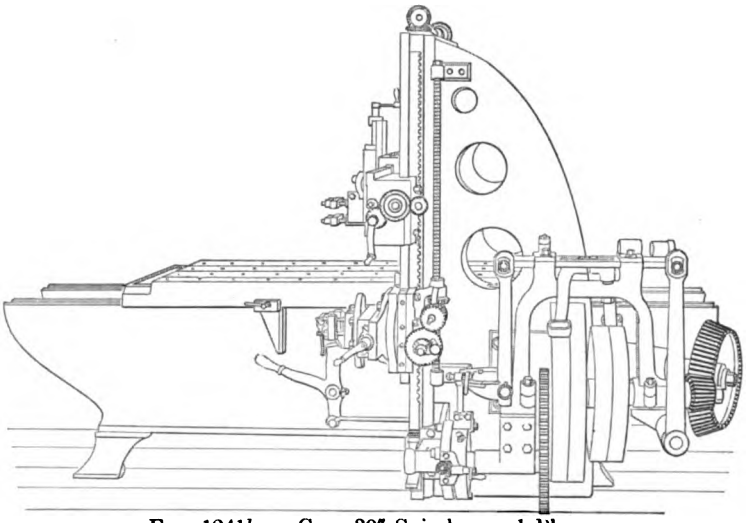

FIG. 1241*b*. — Gray 30″ Spiral-geared Planer.

to advantage many planers are designed with a speed far in excess of the 24 feet mentioned, 40 feet or more being common. Some electrically driven planers have a variable speed control which will give speeds of 90 feet and 100 feet per minute.

1242. Description. A standard type of the modern planer consists of a *platen* or *table*, which slides in V-shaped or flat guides on the top of the *bed*. Heavy *housings* are securely bolted to the bed, the movable *cross-rail* being bolted to the front facings of the housings. This cross-rail carries the *saddle* to which is attached the *planer head*. This head is equipped with a *slide* operated by the *down-feed handle;* bolted to this slide is the *tool-box* for holding the tools. The saddle is moved along the cross-rail by means of a *feed screw*, operated automatically or by hand as desired; likewise, the slide is operated either automatically or by

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hand by means of a *feed rod.* The platen is reciprocated by means of gearing connected to *driving and reversing pulleys.* The length of the stroke and the direction in which the platen moves are governed by adjustable *tappets* or *dogs* which engage a *reversing lever* connected in turn to *belt-shifting levers.* Screws within the housings are used to raise and lower the cross-rail.

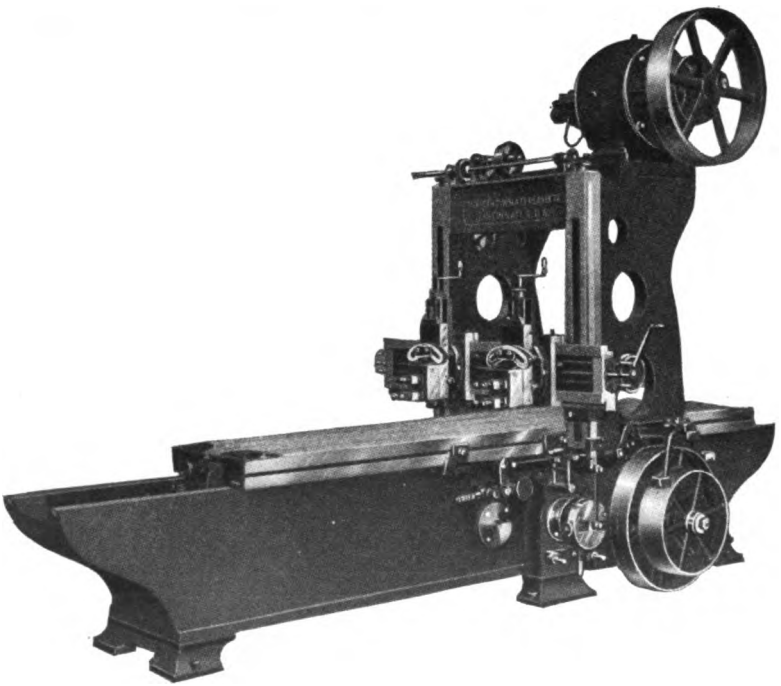

FIG. 1242. — Cincinnati 36″ Spur-geared Motor-driven Planer.

These screws are made to operate simultaneously by means of bevel gears.

1243. Characteristic Operations. It is important to understand the following operations and adjustments of the planer before starting to work:

1. The method of raising and lowering the cross-rail, and the adjustments of the slide; these should be close to the work to avoid the springing of the tool.

2. The correct method of setting the tool, and the adjustments of the tool-box so as to give the tools the necessary relief on the return stroke.

3. The adjustment of the tappets or dogs to give the required length of stroke.

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4. The method of stopping the platen or table and starting it in either direction without stopping the machine. *Caution.* This method should only be resorted to in cases of accident or emergency. *Always* stop this, or *any other machine* for taking the measurements, or when it is necessary to leave the machine, if only for a moment.

5. The method of adjusting the automatic feed mechanism; how to obtain a desired width of cut.

6. How to instantly throw the horizontal or vertical feed into or out of action.

PLANING

1251. Preparation of Work. Prior to fastening planer work in the vise or to the platen it should be laid out to the drawing in accordance with the instructions given under the subject "Laying Out," Sec. 711, in Chapter VII. After the preparatory process of laying out the work, a suitable method of fastening the work or piece for the planing operation should be selected. If the work be large it may be fastened in some of the following ways: it may be bolted directly to the platen; it may be fastened by means of "U-" clamps and bolts; or it may be secured by means of planer pins and toe dogs, or a combination of these methods. When clamping work it is important that the points of clamp pressure be located directly over the points of support and that the work be securely backed up and fastened to prevent subsequent slippage. Leveling wedges, planer jacks and various other devices are used to effect a workmanlike job of fastening. The surface gage is used in bringing lines or surfaces parallel with the table. When the line on the work is to be set parallel with the line of motion of the table, it may sometimes be necessary to place the surface gage at some convenient position on the slide, or in the position of the tool; and then move the table and the work under the cross-rail. The movement then of the platen and work under the cross-rail will indicate at the scriber point the condition of the setting. Work that is not too far from the edge of the platen may be calipered from the line to a straight-edge placed against the side of the platen.

Light, small work of convenient shape is generally held in a vise. Whether held in a vise or not the work should be so placed that the tool will travel lengthwise over its largest surface. If

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the work is too thin to project above the jaws of the vise, parallel blocks of sufficient thickness are used. While tightening the vise the work should be struck lightly with the copper hammer to keep it firmly seated.

1252. Cutting Speeds. The cutting speed of planer tools is governed by the same laws that govern the cutting speed of tools in general, and should vary not only with the character and texture of the metal, but also with the kind of cut. With the planer, which is designed and speeded for taking very heavy cuts on hard material, after the cutting speed has once been determined, it cannot be altered, unless some variable speed device is provided. The fixed rate of speed at which planers operate, except those for high-speed steels, is about 24 feet per minute, which, though making it an admirable tool for heavy cuts on hard material, puts it at a disadvantage for light cuts and such soft material as brass. The crank shaper, however, is provided with cone pulleys and back gears, which, with the adjustable stroke, provide a suitable range of cutting speeds. With the belt on any particular step of the cone, the ram makes a constant number of strokes per minute, whether the strokes be 1 inch or 1 foot in length. If the stroke be 1 foot long and the number of revolutions 60 per minute, we have one stroke forward and one stroke backward of the ram, for each revolution, which gives in a 2 to 1 quick return shaper a varying cutting speed approximating 90 feet per minute. With the other conditions unaltered, if the stroke be shortened to 2 inches, we have the ram moving 2 inches forward and 2 inches backward, occupying the same time as the previous operation and securing a cutting speed of but 15 feet per minute.

Owing to the construction of the shaper and the lack of rigidity in the work, tool and ram, the cutting speeds for planing operations will be found somewhat lower than those for turning, milling and drilling. For this and other reasons the cutting speed for planing is about ½ that for turning operations. The workman is advised to consult the table and chart in Secs. 424 and 429, chapter IV on "Cutting Tools," for further information on this subject.

1253. Planing Practice — Roughing and Finishing — Side and Down Cuts. Surfaces to be planed are usually finished in two cuts, one heavy roughing cut and one light finishing cut. Fin-

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ishing cuts are generally between $\frac{1}{8}\frac{1}{4}''$ and $\frac{1}{1}\frac{1}{0}\frac{1}{0}''$ in depth. When more than one roughing cut is necessary, they should be as heavy as the tool and machine will permit.

Side or down cuts may be made with a properly shaped tool by feeding it down over the sides of the work. For a vertical surface the head should be set at 0 degrees, with the top of the tool-box swung away from the work about 10°.

1254. Planing Recesses and Grooves. In planing recesses or wide grooves cuts should be taken to the desired depth with a parting tool and the remainder of the stock worked out with a diamond-point or round-nose tool.

1255. Planing Bevels or Angles. When cutting bevels or angles, such as V-ways or dove-tailed grooves, swing the head to the desired angle and proceed as in taking a vertical cut.

1256. Under Cuts and T-Slots. When making an under cut or when cutting T-slots, a special tool is necessary. The tool should be blocked by placing a piece of wood between the shank and the head. Where the shank of the tool is short a hinge-shaped device may be attached to its back in such a manner as to lift it clear of the work on the return stroke. These precautions are taken to prevent mishaps caused by the tool catching in the work. In work of this character the feeding is generally done by hand.

As before intimated, planer cuts should always be taken lengthwise of the work when possible, *i.e.*, in the longest direction of the surface.

1257. Cuts Terminating in a Shoulder. For cutting key-ways, slots and cuts terminating in a shoulder, the crank shaper possesses qualities of superiority over the planer, in that the stroke can be more readily adjusted, and when once set will be of exactly the same length each time. Owing to the slip of the belts, and for other reasons, this is not the case with the planer.

A notch with a chisel or hole must be made for cuts that terminate in a shoulder, so that the tool may run out of the cut each time. This notch or hole — which in many cases should have been cored out — must be kept free of chips to avoid breaking the tool.

1258. Accuracy and Errors. Owing to the rigidity of the planer, its work is more accurate than that of the shaper. In the shaper lack of rigidity in the ram and of support to the table causes undesirable spring of both ram and work, especially in

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long pieces. These errors are augmented by any looseness in the gibs and clamping bolts.

1259. Order of Operations for Shaper. Observe the following order of procedure when operating the shaper:

1. *Place the work.* Place the work in the vise so that the tool will travel lengthwise over its largest surface, slip underneath it parallel blocks of sufficient thickness to raise the surface a little above the jaws of the vise. While tightening the vise the work should be struck lightly with the copper hammer, to keep it firmly seated on the blocks.

2. *Adjust the table.* Bring the cross-rail to the proper height, move the table over until the work is in its proper relation with the tool — the tool must just extend over one edge of the surface to be planed — and clamp the cross-rail.

3. *Adjust the tool.* See that the tool is sharp and properly ground, then adjust and fasten it in the tool-post.

4. *Adjust the tool-box.* Set the tool-box over about 10° — not the head; the top of the box away from the work — to obtain the necessary relief on the return stroke.

5. *Adjust the stroke.* Loosen the knob locking the quadrant in position; with the crank handle on the pinion shaft through the knob, move the pointer to the desired stroke and tighten the knob. Pull over to determine the position of the stroke; if incorrect loosen the handle on top of the ram, and push forward or back until correct, then tighten the handle.

6. *Determine the cutting speed.* Calculate it for the piece in hand and then adjust the belt and back gears to secure this speed. Consult the paragraphs on cutting speeds for planing operations, Secs. 424 and 429.

7. *Adjust the feed.* Adjust the feed mechanism — generally coarse for roughing, and fine for finishing cuts; where accuracy may be sacrificed to speed, a coarse feed may be used for finishing — taking care that the feed movement occurs during the return stroke. Down feeding must generally be done by hand.

8. *Pull over by hand.* With all the adjustments made, and the tool in its position over one edge of the work, pull over by hand to ascertain their correctness.

9. *Start the machine. Depth of cut.* Start the machine and feed the tool down by hand until the desired depth of cut is obtained.

10. *Throw in the feed.* Throw in the automatic feed and

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watch the work carefully to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time.

1259½. Order of Operations for Planer. Observe the following order of procedure when operating the planer:

1. *Adjust the work.* If the work be large, it may be fastened — always securely — in some one of the following ways to the platen: It may be bolted directly to the platen; or, it may be fastened by means of U-clamps and bolts; or it may be secured by means of planer pins and toe dogs or a combination of these methods. If the work be small and of convenient shape, it may be held in a planer vise; place the work in the vise so that the tool will travel lengthwise over its largest surface, slip underneath it parallel blocks of sufficient thickness to raise the surface a little above the jaws of the vise. While tightening the vise, as already noted, the work should be struck lightly with the copper hammer, to keep it firmly seated on the blocks.

2. *Adjust the tool.* See that the tool is sharp and properly ground, then adjust and fasten it in the tool-box.

3. *Adjust the tool-box.* Set the tool-box over about 10° — the top of the box away from the work — to obtain the necessary relief on the return stroke.

4. *Set the cross-rail and saddle.* Bring the cross-rail and saddle into their proper relation with the work; the tool just over one edge of the surface to be planed.

5. *Adjust for travel.* Set the tappets or dogs to give the desired length of stroke; this should be about ¾″ longer than the cut. In the extreme forward position give about ¼″ over travel.

6. *Adjust the feed.* Adjust the feed mechanism — coarse or fine as the work in hand demands — taking care that the feed movement occurs during the return stroke.

7. *Pull over by hand.* With all of the adjustments made and the tool in its position over one edge of the work, pull over by hand to ascertain their correctness.

8. *Start the machine.* Start the machine and feed the tool down by hand until the desired depth of cut is obtained.

9. *Throw in the feed.* Throw in the automatic feed and watch the work carefully to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time.

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CHAPTER XIII

MILLING

Milling Machines

1311. Ordinary Types. Any machine that, while holding the work, operates upon it with a revolving cutter or mill, may be termed a milling machine. The three common types of milling machines are the plain, the vertical and the universal.

1312. Plain Milling Machines. Plain milling machines are designed for finishing surfaces that may be fed to the cutter in a straight line. They are usually arranged so that the work may be fed to the tool vertically and in two horizontal directions at right angles to each other. In this type of machine the spindle and the axis of rotation of the cutter are generally horizontal.

1313. Vertical Milling Machines. Vertical milling machines are so designated because the spindle and the axis of rotation of the cutter are vertical. Such machines usually have, in addition to the vertical and two horizontal feeds of the plain milling machine, a method of revolving the work in a horizontal plane for finishing circular surfaces.

1314. Horizontal Milling Machines and Rotary Planers. Horizontal milling machines are generally built for heavy straight work and resemble in a way the conventional planer with its deep bed and long platen or table and its characteristic housings; however, these machines partake of the ideas of their originators and to that extent are made in widely varying shapes and designs, according to the class of work they are to perform. These machines generally have two, three or four spindles, each of which carries its own mill and is independent in adjustment. As the construction would indicate, in most instances the table and work are movable in one direction only, the mills operating simultaneously on the several surfaces of the work. In a typical machine the table has a quick power movement of 20 feet per minute and is equipped with power feeds of from 1″ to 12″ in either direction, per minute.

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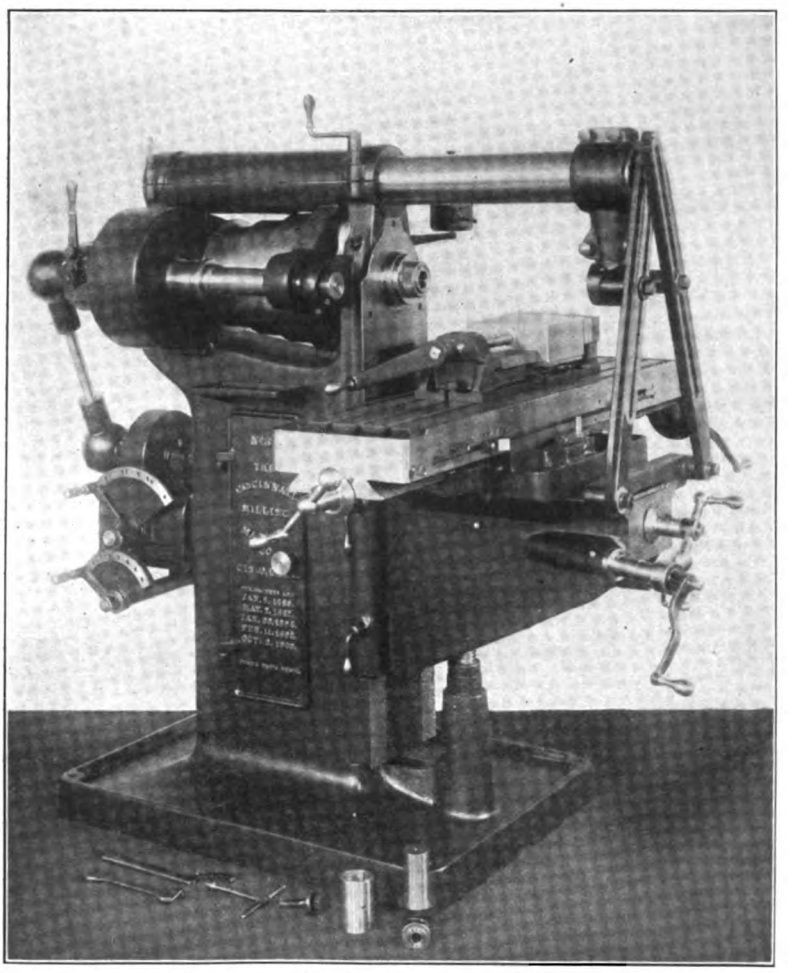

FIG. 1312. — Cincinnati Plain Milling Machine.

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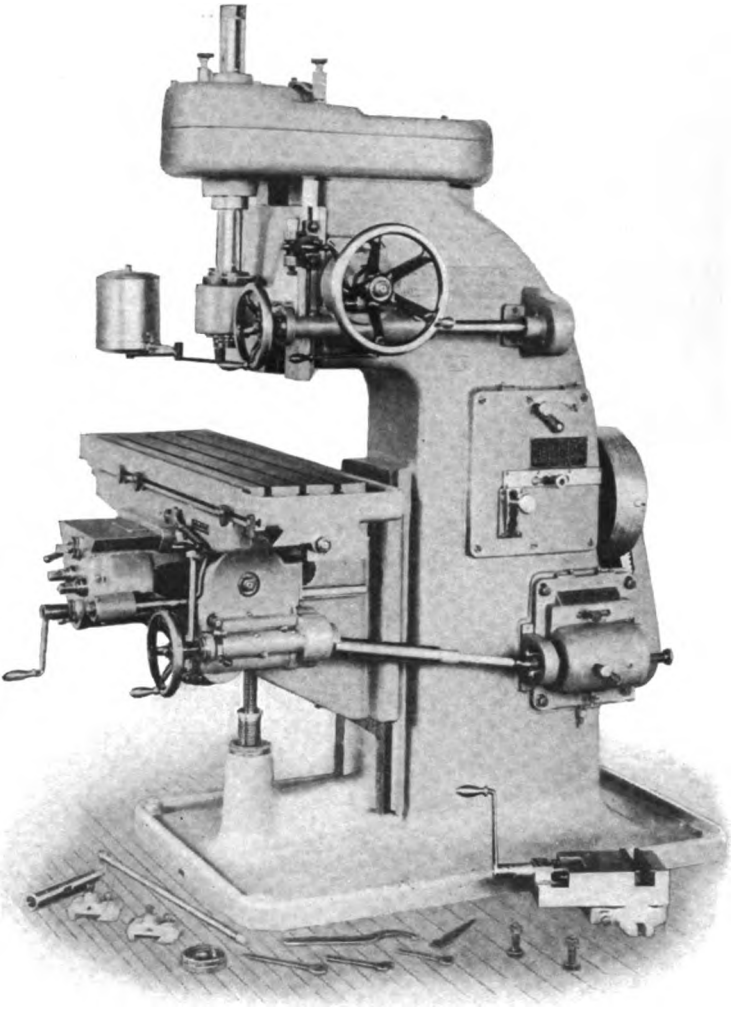

FIG. 1313. — Brown & Sharpe Vertical Milling Machine.

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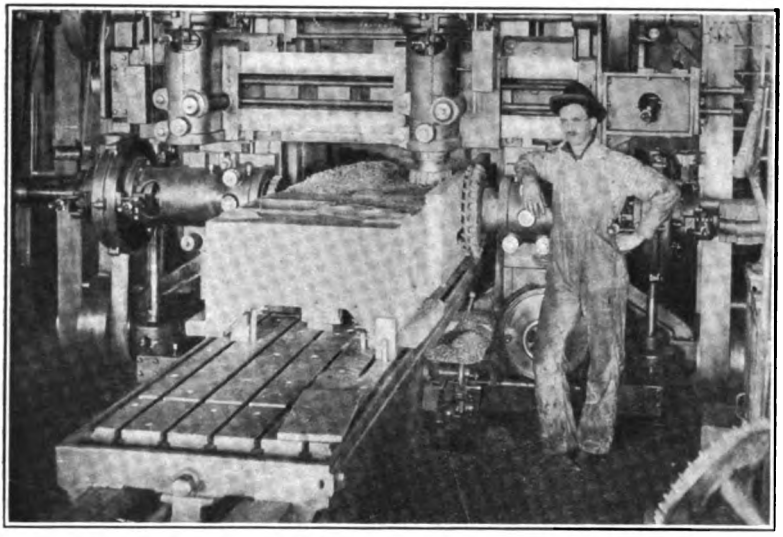

FIG. 1314*a*. — Ingersoll Four-head Horizontal Milling Machine.

The rotary planing machines on the market are, according to definition, nothing more or less than a type of horizontal milling machine. The deep, rigid bed, instead of carrying the table, carries the cutter head — an inserted tooth mill — and its opera-

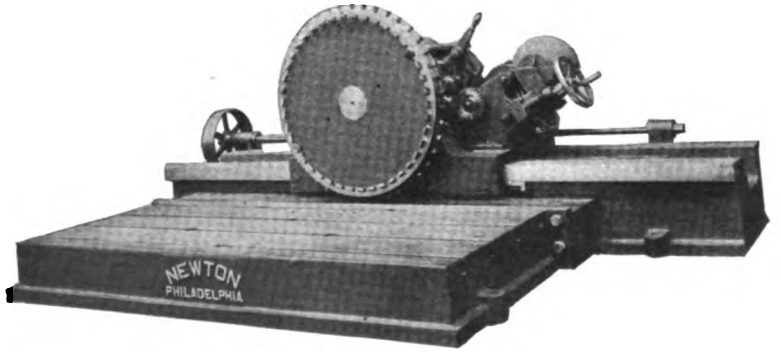

FIG. 1314*b*. — Newton Rotary Planer, Motor-driven.

ting mechanism. The work is generally stationary, while the cutter head, which is often very large (84″ in diameter) is moved over the surface operated upon.

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1315. Universal Milling Machines. Universal milling machines are generally equipped with such a variety of attachments that they can be used for almost every conceivable milling operation within the capacity of the machine. An indexing or universal dividing head is always furnished with the universal machines.

The Universal Miller and Attachments

1321. Functions and Limitations. As has been stated, universal milling machines are generally equipped with such a variety of attachments that they can be used for almost every conceivable milling operation within the capacity of the machine. A special attachment makes it possible to rotate the work while it is being fed longitudinally in a horizontal direction, thus producing helical or spiral work. The horizontal feeds, in addition to working at right angles to each other, can be made to operate at any desired angle within the limits of the machine. The table may sometimes be completely revolved through 360 degrees.

Regarding limitations and errors, it may be stated that with the use of a sharp cutter and a high-grade milling machine operating under favorable conditions, work may be turned out with the small limit of variation of one one-thousandth of an inch. The usual limit which obtains in the ordinary milling practice for such rough work as the square ends of reamers and taps and the faces of bolt heads and nuts is about four one-thousandths of an inch, and for a finer class of work, such as the various parts of fire arms, sewing machines and typewriters, the parts are finished within a limit of variation of two one-thousandths of an inch.

1322. Description of Parts. An advanced type of universal milling machine — the Cincinnati — has the following construction and parts: A *frame* or *column* that supports the machine, the inside of which is often used as a closet. The *spindle* for rotating the *cutter arbor* is hollow and has at its front end a Brown & Sharpe taper hole; this end of the spindle is also threaded to receive a universal chuck. The spindle carries a *cone pulley* which receives its motion from a similar cone on a *double-speed* countershaft. Many machines are equipped with *back gears*, operated similarly to those of the ordinary lathe, for increasing the number of speed changes. The universal chuck provided, fits both the spindle and the dividing head and may be used on the spindle for holding straight-

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shank reamers, drills, boring bars and special cutters. The *overhanging arm*, which may be swung out of the way for end milling, supports the outer end of the cutter arbor with a bearing; this bearing is so constructed as to admit of being concentrically closed in as wear takes place. The main frame is of box form with its face side planed to receive the *knee*, which slides upon it vertically, being raised or lowered by a screw operated by a pinion

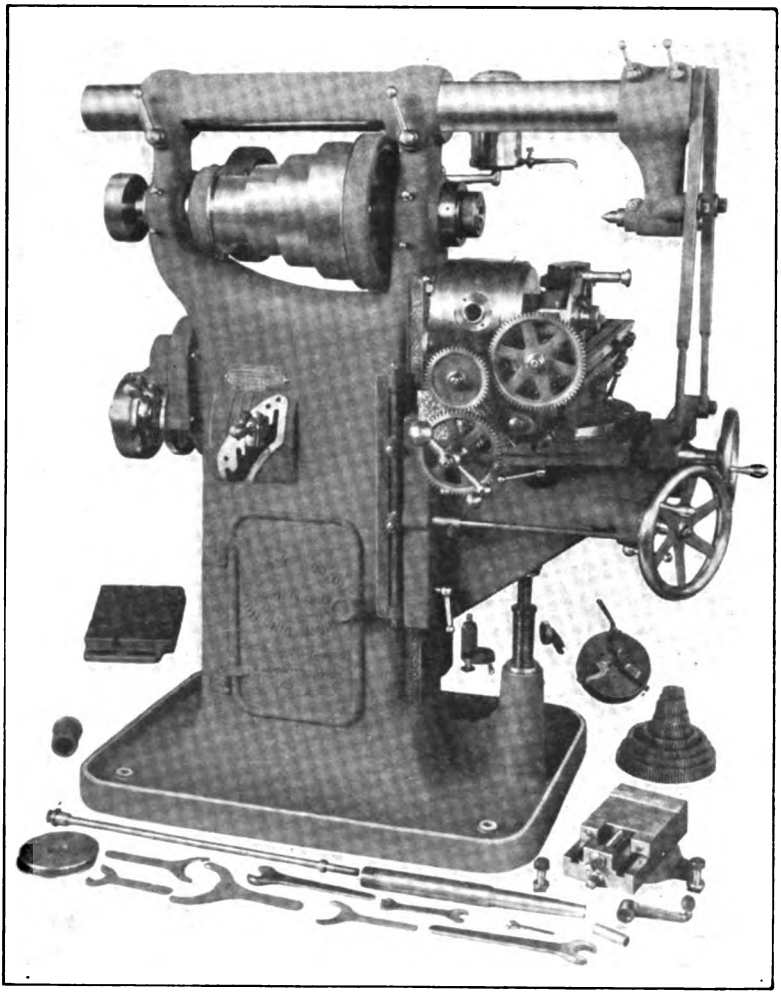

FIG. 1322. — Hendey-Norton Universal Milling Machine.

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shaft, which has on the outer end a detachable clutch handle. The *saddle* is placed on top of the knee and is operated by the transverse screw in a line parallel to the axis of the main spindle. The *swivel carriage* — circular in form — on top of the saddle, provides a substantial support for the *table* at whatever angle it may be placed; this swivel member is firmly bolted to the saddle by means of easily accessible "T"-head bolts. The power for driving the table is obtained from a small cone pulley on the rear end of the main spindle. For the slower feeds, this pulley is clutched directly to the spindle; and for the faster feeds runs loose on the spindle. While loose on the spindle this cone is driven by a gear arrangement which increases the rate of feed between two and three times. For this heavier duty of rapid feeding a higher belt speed is obtained. By raising the hand lever these gears are thrown out and at the same time the clutch on the small cone pulley is engaged with the clutch on the end of the spindle, or *vice versa*. Eight changes of feed, varying from .004″ to .070″ travel of the table to one revolution of the cutter are provided, while a plate near the feed mechanism lever indicates the rate at which the machine is feeding.

The rapid introduction of high-speed steel cutters has rendered imperative higher and more powerful feed mechanism and most milling machines are now equipped with positive feed devices. On the machine being described the positive feed mechanism consists essentially of two parts, an upper *gear box* at the rear end of the spindle and a lower gear box at the rear of the column. These two are connected by means of a vertically inclined shaft. Two speeds are imparted to this shaft for every speed of the spindle by means of a *sliding gear* in the upper box. This shaft in turn drives two *feed gears* in the lower gear box. These feed gears drive the two nests of *cone gears* which run loose on their shaft, independent of one another; the larger feed gear engaging the smallest gear on one cone and the smaller feed gear engaging the largest gear on the other cone, thus imparting widely different speeds to the two cones. From these cones, motion is transmitted to the various feed screws, through an intermediate gear, which is made to slide on the shaft by means of a *rack* and *sector*, and placed into correct position for engaging any one of the cone gears by means of the lever which actuates the sector. The position of this lever, at any time, indicates the rate at which

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the machine is feeding, in thousandths of an inch, per revolution of the spindle, by means of raised figures on the *lever quadrant.* On a No. 1½ Universal Machine there are 12 feed changes: .005, .008, .011, .016, .023, .030, .042, .063, .095, .136, .190 and .253 inch per revolution of the spindle.

The lower lever having been placed in position, to obtain the desired rate of feed, the intermediate gear is brought into mesh with the proper cone gear by the *upper lever* (on lower gear box), which moves the entire lower portion of this mechanism. This is accomplished by means of a helical groove in the hub of the lever which engages a pin in the slide, upon which are mounted the *lower lever,* sector, *rack* and intermediate gear. It is evident that this mechanism makes possible a large number of feed speeds and that the changes to secure a given feed can be made in the short space of time required to shift the levers.

The motion is transmitted from the lower small feed cone, or the lower gear box, by means of a universal jointed, telescope shaft to the *stem gear* which has its bearing in the back of the knee, and thence through a splined shaft to the *cross-feed screw.* The direction of the power feed is changed by operating the *tumbler gear* through the crank. The operation of the automatic power cross-feed is as follows: the splined shaft has a clutch pinned to its outer end for engaging another clutch attached to a pinion operating the feed screw. The cross-feed is operated by a hand lever and may be thrown out automatically by means of trip dogs; it may also be operated by hand.

The motion for feeding the table is imparted from the same splined shaft as that operating the cross-feed screw. Sliding on it is a bevel gear which transmits its motion through a vertical shaft, a pinion and gear to another vertical shaft centrally located within the carriage. On the upper end of this shaft a bevel gear meshes with a companion gear on the lead screw. This gear is journaled in the carriage and has clutch teeth for engaging a feathered clutch, sliding on and operating the lead screw. The hand-lever engages and disengages this clutch for starting and stopping the automatic table feed. On the front of the table, in "T" slots, wedge-surfaced trip dogs are provided for automatically disengaging this feathered clutch. Two handles, one at each end of the table, are provided for feeding by hand. The handle on the left end of the table is used for fine feeding; the one on the

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right end, a clutch crank, is used for rapid feeding and quick return. This clutch crank is also used on the shaft controlling the vertical motion of the knee. *All adjustments, indicated on the dials, are in thousandths of an inch.*

1323. The Universal Dividing Head. The universal dividing head finds its greatest use in the division of the circumference of cylindrical work into a large range of equal parts. It is also used for helical (spiral) work, such as twist drills, spiral teeth on cylindrical and conical milling cutters; also the teeth of spiral, spur and bevel gears.

Note. It is to be deplored that the words helix and spiral are synonymous terms to many mechanics. Grooves and gear teeth, that are in reality helical, are erroneously termed spiral. In accordance with the mathematical definitions of the terms, the most familiar example of a helix is a screw thread; of a plain spiral, a clock spring; of a conical spiral, a conical bed spring. By common acceptance, the word spiral, when applied to milling operations, gear teeth and cutters, means helical.

This dividing head is an attachment so designed that, while holding the work, it will rotate it through any desired angle or fraction of a revolution. An example will be found in the rotation of a gear blank through an angle corresponding to the pitch; thus is the blank moved forward so that the cutter may form a new tooth. When cutting spirals suitable gears, mounted on a segment plate, are attached from the lead screw to the dividing head for rotating the dividing head spindle. Two tongues in the base of the head housing fit in the "T" slot of the table to which it is bolted. That the spindle may be inclined at any desired angle, it is carried on a swiveling block fitted in the housing. The same arbor and chuck which fit the main spindle will fit the head spindle, which is likewise hollow. The head spindle can be firmly locked during the cutting operations, thus relieving the worm, worm wheel and index pointer of all strain. Formed on this head spindle is a worm gear having 40 teeth, which arrangement necessitates, for one revolution of the spindle, 40 complete revolutions of the index pointer shaft, which is used in connection with an index plate, a sector and a pointer, for dividing the work. Thus one turn of the crank on the index pointer shaft gives $\frac{1}{40}$ of a revolution of the spindle; two turns, $\frac{1}{20}$; four turns, $\frac{1}{10}$, etc. For other divisions, the index plate, over which the

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pointer crank turns, is used. This index plate is a circular disc on which a number of circles are arranged, each circle being divided by means of small, accurately spaced holes, into a different number of equal parts. If the pointer on the crank be so adjusted that the pointer comes in line with the holes of any one circle, we may divide each revolution of the spindle into as many equal parts as 40 times that number of holes in the circle; or indeed any factor of that number of parts.

The following is the method of procedure for obtaining any number of divisions (faces or teeth) of the circumference of the work. Consulting the table furnished with the machine, we find in the column headed "No. of Teeth or Divisions," the number we desire. On the same line in the next column headed "Circle" is given the number of holes in the circle to which the index pointer must be set. In the third column headed "Turns" is given the number of complete revolutions of the pointer crank; and in the fourth column headed "Holes" is given the number of holes in that circle, to be added for each new setting. The function of the sector is to obviate the necessity of recounting each time this number of holes. In setting for a given number of holes, 12 for instance, a mistake is liable to be made in setting the sector, by including between its beveled edges but 12 holes; this is incorrect, for the *hole* in which the index pointer is inserted should *never be* counted when adjusting the sector. After the sector is set and tightened by the screw, no further counting of holes is necessary, because the sector, as set, is moved against the index pointer for each new division.

When no table is available the setting may be easily calculated as follows: write the fraction whose numerator is 40 and whose denominator is the number of teeth or divisions. This fraction represents the ratio that exists between the number of holes and the circle on which these holes are to be counted. Example: Required the setting for 180 divisions or teeth: $\frac{40}{180} = \frac{4}{18} = \frac{8}{36} = \frac{12}{54}$, which means that if we select the circle marked 18, we must use 4 holes; if 36 be selected, 8 holes, and if 54 be selected, 12 holes. Again, suppose that it is desired to obtain 17 divisions: $\frac{40}{17} = \frac{80}{34} = \frac{120}{51}$, which means that if we select the circle marked 17 we must use 40 holes on it; *i.e.*, 2 turns plus 6 holes; if 34 be the circle chosen, we must use 80 holes, which is two turns plus 12 holes.

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1324. Index Drum. In many machines, to facilitate the dividing of the work into parts less than 40, and to admit of starting the divisions at any desired point after the work has been set, an index drum, adjustable on and bolted to the spindle, is often used.

1325. Tail-stock. The tail-stock furnished with the machine may be briefly described as follows: It is fastened to the table in the same manner as is the dividing head and carries two centers which are adjustable vertically and longitudinally by special adjusting knobs. Clamping bolts are provided for holding the centers firmly in position after they have been set. One center has the top milled off to allow small work, such as taps and reamers, to be milled; the other end is left as full as possible for heavy work. The change from one center to the other is easily effected.

1326. Raising Block. For special work, generally chucked on the head, it is sometimes required that the axis of the head spindle be at an angle, in a horizontal plane, to the line of motion of the table. For such cases a raising block, a plate having two "T" slots at right angles to each other, is used. This block is bolted to the table so that one of its "T" slots forms the desired angle, and in this slot the head is bolted.

1327. Swivel Vise. For holding a certain class of small work, a swivel or milling machine vise is used. This vise is so arranged that it can be rotated and clamped in any desired position on the table.

1328. Steady Rest and Other Attachments. To prevent springing and chattering in such thin and slender work as is held between the centers, a steady or center rest is provided.

The oil tank and drip cup should always be properly adjusted and used for all milling operations in wrought iron and steel.

The other milling attachments, not furnished with the machine, but which may be purchased, are the circular or rotary attachment, the vertical milling attachment, the profiling or cam-cutting attachment, the rack-cutting attachment, the high-speed attachment and the slotting attachment.

1329. Characteristic Operations. It is important to understand the following operations and adjustments of the milling machine before starting to work:

1. How to adjust the work in its relation to the cutter so

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that, when possible, all the milling operations may be performed upon it without disturbing this adjustment, whether it be placed between centers, on the table, in the vise or in the chuck.

2. How to select and assemble the proper cutters and arbors. The care and thought expended here is sure to be fruitful.

3. The calculation and adjustments of the belts and gears to secure the proper cutting speeds and feeds.

4. The means by which the various motions of the table are effected.

5. The method of raising and lowering the saddle and the means of controlling the movement of the table.

6. How to reverse the direction of the feed and the method of instantly stopping it.

7. The method of determining, by means of the various dials, just that relation of the work to the cutter that will insure its operating where desired.

8. A fundamental knowledge of the principle involved in the method of dividing with the dividing head, using either the dial or index drum.

9. How to make the necessary gear calculations and adjustments for the various kinds of helical or spiral milling.

10. The use of the raising block, swivel vise and steady rest.

Milling

1331. Preparation of the Work. As was the case in the other machining operations before placing milling work in the machine in its proper relation to the cutter, it should be laid out to the drawing in accordance with the instructions given in Secs. 711 and 712, Chapter VII. Of the varied stock which comes to be operated upon in the milling machine, unannealed tool steel is likely to give the most trouble on account of its liability of being either hard in spots or all over. Forgings, too, often offend in this manner, the hardness in any case resulting in a rapid dulling of the cutter. Both iron and steel castings usually possess a thin skin or scale which, because of its hardness and imbedded particles of sand, must be removed before a mill can operate successfully upon it. The accepted method of removing hard spots from tool steels is by annealing. Scale may be removed tolerably well by tumbling the smaller castings in a foundry rattler. A better method, and one adapted to larger castings and

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scaly forgings as well, is to pickle the castings, the process of pickling being as follows: the pieces so treated are washed with, or immersed in, a solution of 1 part of commercial sulphuric acid to from 4 to 10 parts of water. After the acid has had time to act — ten to fifteen minutes — the pieces are thoroughly washed in clean boiling water to remove all traces of the acid, which would otherwise cause them to rust rapidly. The crumbling scale will now be found to be easily removed by means of wire brushes and old files. If, after pickling, the pieces are still too hard, they should be heated to a dull red heat and allowed to cool slowly, this annealing process tending, in addition to softening the piece, to release any shrinking and working strains that are inherent in it.

1332. Nomenclature. — Terms and Operations Defined. When metal is removed by means of a cutting tool rotating about its axis and having one or more cutting edges, the operation is termed milling and the cutting tool is called a mill or cutter. Ordinary milling operations admit of the following classification: *Face milling* — machining a plane surface parallel to the axis of rotation of the cutter; *side milling* — machining a plane surface perpendicular to the axis of rotation of the cutter; *angular milling* — the machining of a plane surface at an angle to the axis of rotation of the cutter; *form milling* — the machining of irregular or curved surfaces having a profile similar to that of a cross-section of the cutter; *grooving* — the making of straight, "T," irregular or helical slots or grooves; *profiling* — referring to such milling operations as require the use of a templet for guiding the work in any desired direction; *routing* — referring to such milling operations as require that the work or the tool be fed by hand.

1333. Influence of Cutter Diameters. The diameter of the milling cutter should be as small as the strength and convenience will permit. If it be desired to remove the amount of stock, 1, 2, 3, 4, by one of the two cutters shown in Fig. 1333, it is obvious that the large cutter LC must travel the distance X during the operation, while the small cutter SC travels through the distance Y in performing the same operation; the small cutter thus effecting a saving in time equivalent to the ratio which Z bears to X. If the length of the cut be short, the distance Z, the percentage saved, forms no inconsiderable portion of X,

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the total time. Again, small cutters cost less and require less power to drive them than large cutters.

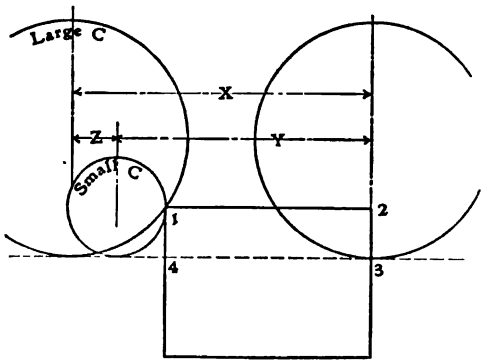

FIG. 1333. — Influence of Cutter Diameters.

1334. Assembling Cutters, Collets, Collars, etc. As has been stated before, in assembling the cutters, collets, collars and arbors they should be clean and carefully wiped dry to insure a true running cutter. A small piece of grit between the faces of the cutter and collar would cause the arbor to spring and the cutter to run out of true.

1335. Feeding and Speeds. When it is desired to mill the end of a piece of work, the work should be so placed as to feed up and against the cutter as is the case in horizontal milling. This brings the pressure of the cut down upon the top of the table, with a tendency to close all the joints between the table, saddle and knee, insuring a smooth, steady cut.

The following are the signs of excessive feed and speed: too high a cutting speed is attended by a rapid dulling of the cutter and subsequently a squeaking sound; slippage in the driving or feed belts may cause them to squeak or run off and is indicative of excessive feed.

For knowledge relative to milling speeds and feeds the workman is referred to Secs. 424 and 429 of Chapter IV.

1336. End Milling Slots. When milling a slot with an end mill that necessitates the use of both sides of the cutter at the same time, the direction of the feed is determined from a consideration of the amount of stock to be removed from the sides; that surface from which the greatest amount of stock is to be removed should be fed against the cutter. The deeper cut *against*

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the cutter, with its tendency to retard the feed, reduces to a minimum the danger resulting from the drawing action of the lighter cut *with* the cutter.

1337. Cutting Action of Face, Side and End Mills. Contrasting the action of face, side and end mills, we find that the tendency to spring and distort the work is greater with the face cutter, though the pressure is largely down or at right angles to the cut, while with the side and end mills the greatest pressure is in the direction of the feed. Face mills produce smoother surfaces and require less care and grinding to keep them in good condition.

1338. Swivel Vise Adjustments. When no zero mark is placed on the base of the vise, it may be adjusted to zero by placing between the centers a true, cylindrical piece of work and adjusting the vise so that the entire length of the jaw rests against the work. By the use of the try square, with the beam against the work and the blade against the inside of the jaw, a right angle to the first setting is obtained. *Caution.* For these operations care should be taken to see that the table is set at the zero mark on the swivel carriage.

1339. Order of Operations. Observe the following order of procedure when operating the milling machine for plain milling operations:

1. *Adjust the work.* Adjust the work between the centers, on the table, in the vise, or in the chuck, using that form of device for holding it which seems, after due consideration, to be the best. Make sure that the work is immovable and securely fastened, and if between centers, that the tail of the dog is clamped with the set screw, and also that the tail center clamping bolts are tightened. If the work be held in the chuck, allow that portion to be milled to project away from the jaws.

2. *Select cutter.* Select that milling cutter best adapted, as to kind and diameter, for the work in hand. Place it on the arbor as close to the spindle as possible and so that, when running *normally*, the teeth cut *down*. Before assembling, the arbor, collet or socket, cutters, bushings and bearings should be wiped dry with clean waste. Insert the arbor in the spindle, oil the outer end and adjust it in the overhanging arm, clamping the arm when in position.

3. *Adjust table and carriage.* In order to bring the work into

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its proper relation with the cutter, adjust the table and the carriage so that the work feeds against the cutter, *i.e.*, the work to the right of the cutter when the latter is rotating to the left (Fig. 1339). To avoid accident or irregularity with the cut, take up all back-lash of the lead and cross-feed screws. As all the adjustments are given on the dials in thousandths of an inch, we may use them, in some instances at least, for determining ap-

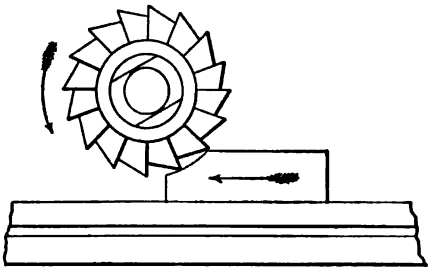

FIG. 1339.

proximate dimensions and cut depths. In working from the center, the table is adjusted until the cutter, or the side of the cutter, is central; in this position the pointer is set to the zero on the dial, when the screw is turned a distance equal to half the width of the piece. As this method of setting is somewhat inaccurate, it is better to err on the safe side and to check all measurements with the scale.

4. *Determine speed and feed.* After having selected the proper speed and feed by calculation or from the tables in Secs. 424, 428 and 429, Chapter IV, which deal with milling speeds and feeds, adjust both the driving and feeding belts or feed box.

5. *Adjust the stop.* Adjust the trip dog or stop so as to disengage the automatic feed before the cutter meets any obstruction, *i.e.*, at the end of the cut.

6. *Ascertain correctness of adjustments.* If necessary, lower the knee and run the work past the cutter, both to determine the correctness of the adjustments and to see whether any obstruction to the cut will be met with during the operation. If this be done the work must be brought back to its original position, the knee raised and all backlash taken up.

7. *Pull over by hand.* With all adjustments made, pull over by hand to ascertain their correctness and to avoid breakage.

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8. *Determine cut depth.* Determine the depth of the trial cut *by measurement.*

9. *Adjust drip pan and oil tank. For wrought iron or steel* adjust the oil tube over the cutting side of the mill and place the drip pan where it will catch the waste oil and chips; lard oil should be used. Open the oil valve to about thirty drops per minute. Flooding is generally beneficial.

10. *Start the machine.* Do not feed by hand, as any carelessness may result in pushing the work in deeply between two adjacent cutter teeth with the result that the work will be spoiled, the cutter broken, or both.

11. *Throw in the feed.* Throw in the automatic feed and allow the work to feed up to the cutter; watch the work carefully to detect any irregularity in the working of the machine. Be ready to take advantage of every opportunity to save time.

Examples of Milling

1341. Face Milling. Figs. 1341*a* and *b* illustrate the ordinary methods of milling hexagon nuts or bolt heads. In the first

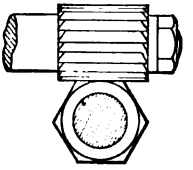

FIG. 1341a

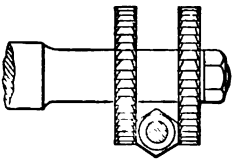

FIG. 1341b

Figs. 1341*a*, *b*. — Face Milling Nut and Bolt Heads.

illustration a face mill is used, and one surface is finished at a time. The straddle mills or cutters in the other example are side mills arranged for finishing two sides at one operation. In either case a number of nuts may be strung on an arbor or mandrel and all finished at one time.

Fig. 1341*c* illustrates the method of milling a number of small pieces and accurately finishing the sides and bottom at one operation.

1342. Slot Milling. Fig. 1342*a* illustrates the final operation in the milling of a "T" slot, the preliminary operation consisting in the removal of all metal possible by means of a face cutter, If a face cutter cannot be used to advantage, the stock may be

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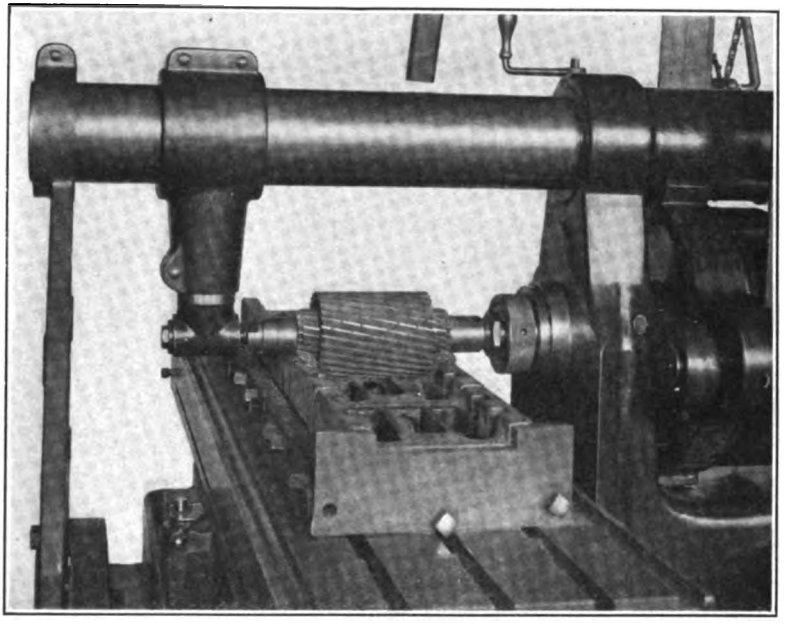

FIG. 1341c. — Face Milling Several Pieces.

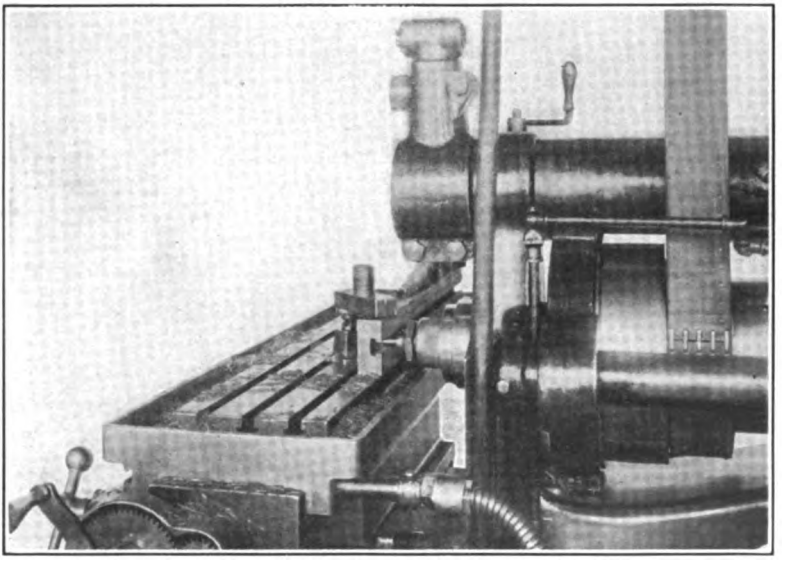

FIG. 1342a. — T-slot Milling, Final Operation.

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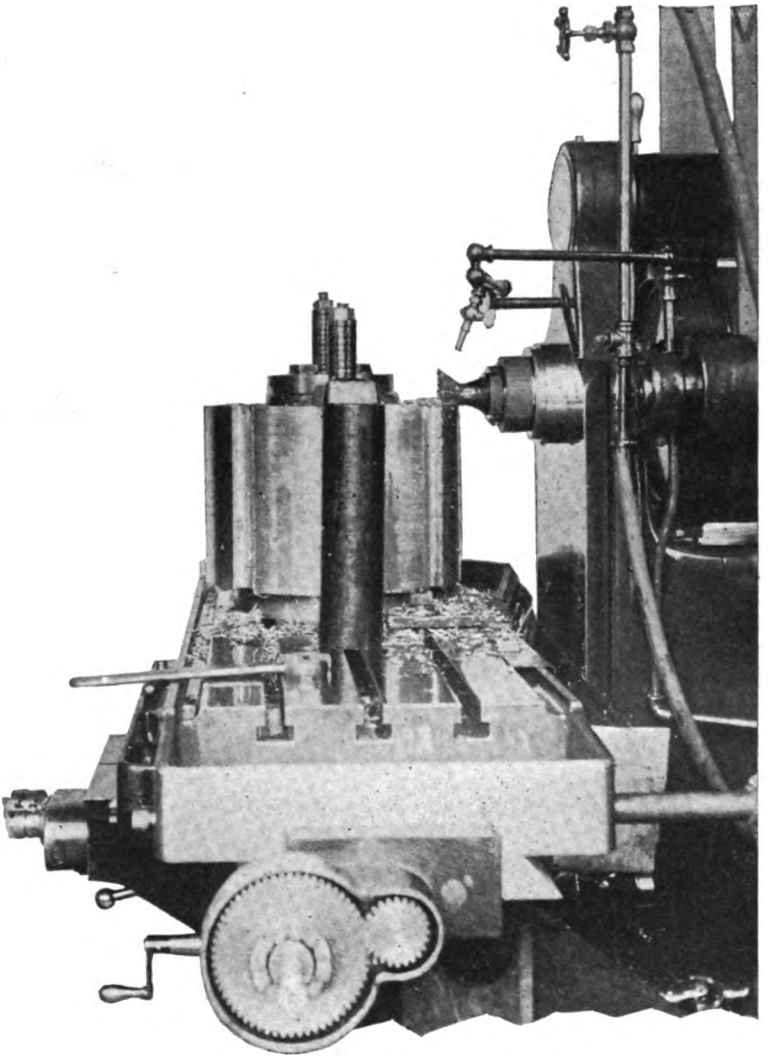

FIG. 1342*b*. — Milling Dovetail Slots.

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removed with an end mill, whose diameter is somewhat smaller than the width of the slot.

Fig. 1342*b* illustrates the final operation in the milling of a dovetail slot, the preliminary operation being the same as that for milling the "T" slot.

1343. Boring and Facing. Fig. 1343*a* illustrates the method of milling the bearing of an engine, finishing both the sides and the bottom at one operation. The figure is suggestive of the variety of work that may be performed on a milling machine with one chucking and cut.

Fig. 1343*b* is suggestive of the various boring, facing and milling operations which may be performed to advantage by either bolting the work to the table, holding it in the vise or between the centers. For long holes it is well to support the outer end of the boring bar arbor in the overhanging arm. It may be noted from this suggestion that by using the vertical and lateral adjustments, work may be readily and speedily set in any desired position for boring parallel holes. In all settings of the table, care should be taken to eliminate all errors that might be due to backlash in the various adjusting screws. In this operation a twist drill or reamer may advantageously take the place of a cutter or boring bar.

1344. Key-seating and Fluting. Fig. 1344*a* illustrates the method of milling several key-seats; with a single piece this may be done by holding the shaft in a vise or between the centers.

Fig. 1344*b* illustrates the method of fluting cutters, taps and reamers. In the case of tapered work the tail center is raised enough to give the proper depth of cut at each end of the flutes.

1345. Gear Cutting, Segment and Spot Finishing. Fig. 1344*b* is also illustrative of the method of cutting a gear or number of gears; when two or more gears are to be cut they are strung on an arbor or mandrel and placed between the centers, the table having previously been adjusted so that the center line of the gear blanks is directly underneath the center line of the cutter. The dividing head is then adjusted to give the correct number of divisions and the table raised until the cutter just touches the rim of the gear blank. Set the graduated dial on the elevating screw to zero, run the blanks out from under the cutter to the proper side and raise the table an amount equal to the required depth of tooth (this latter is generally marked on

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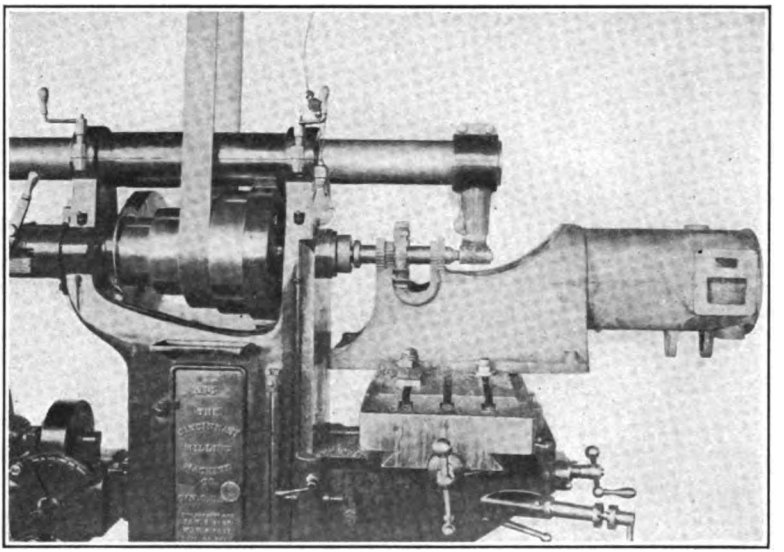

FIG. 1343*a*. — Face and Side Milling Engine Bearings.

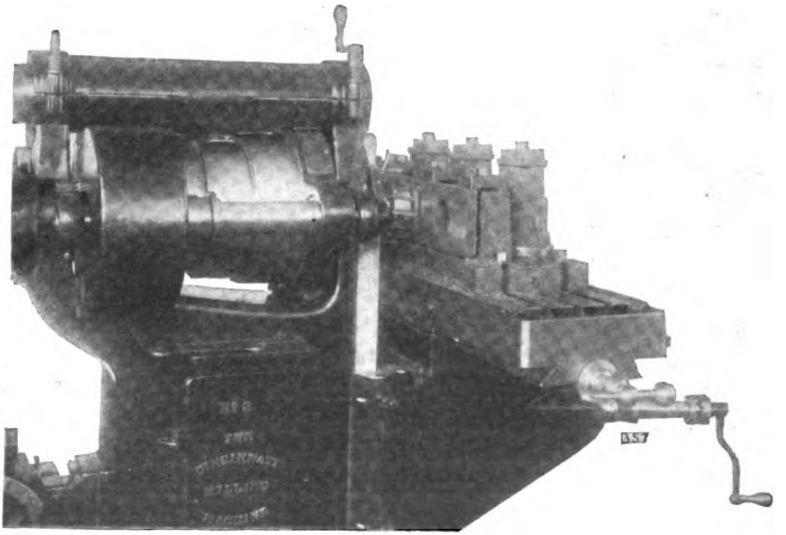

FIG. 1343*b*. — Boring and Facing Operations.

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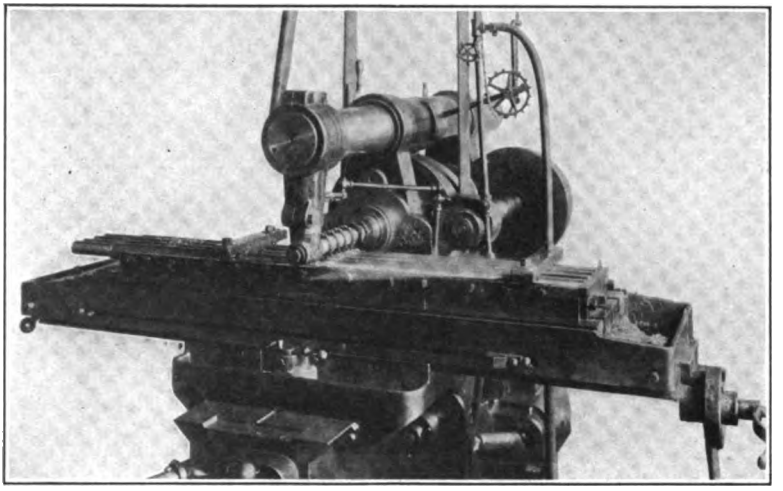

FIG. 1344*a*. — Key-seating Several Shafts at once.

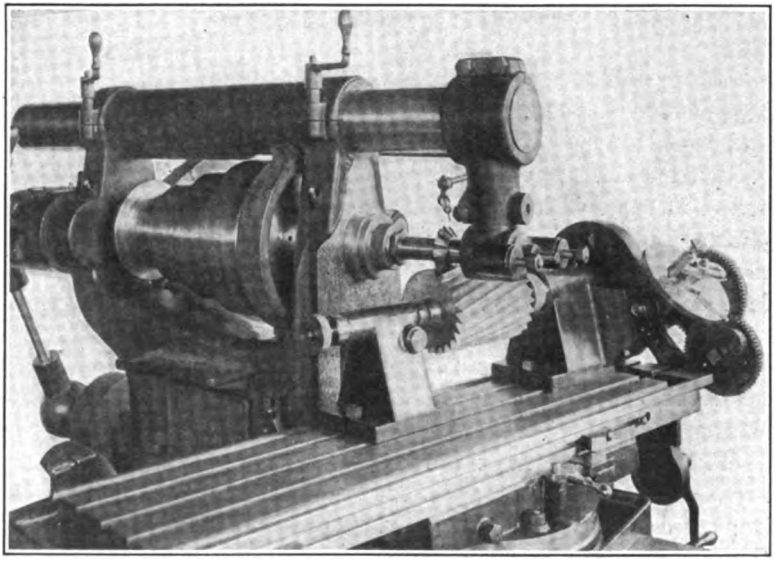

FIG. 1344*b*. — Fluting a Milling Cutter.

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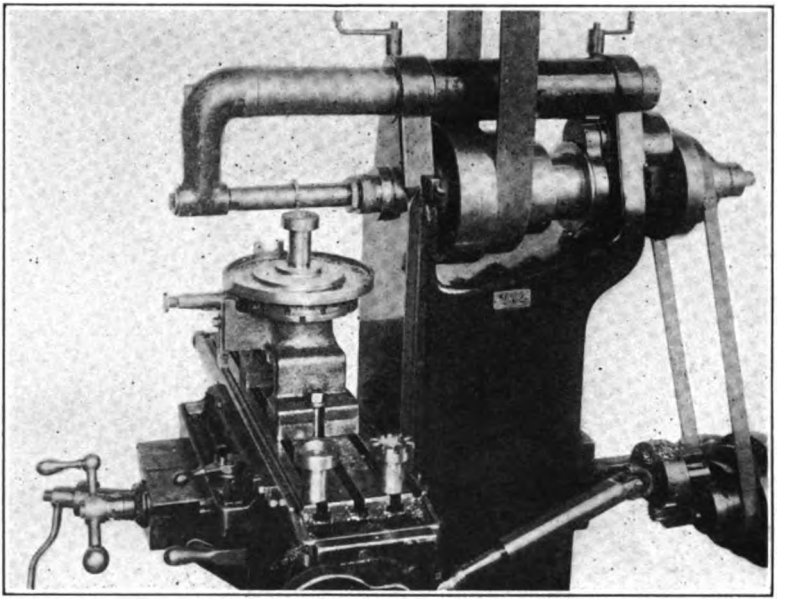

FIG. 1345*a*. — Milling Clutch Teeth.

the cutter). By bringing the index or dividing head spindle into a vertical position, we have a means whereby spur gears, and work too large to be swung between the centers, may be operated upon. The blanks are carried on a vertical arbor inserted in the spindle; this placing of the blanks in a horizontal position necessitates the determination of the tooth depth by means of the lead screw, and of the work being fed by the vertical feed or elevating screw. Fig. 1345*a* illustrates the method of milling clutch teeth.

Fig. 1345*b* illustrates the method — with a vertical milling machine — of end- and side-mill finishing a horizontal plane surface and a vertical segment at one operation.

Fig. 1345*c* illustrates the method — with a vertical milling machine — of finishing spots on the inside surface of a feed-bracket casting with an end mill. The same cutter also finishes the upper edge of the casting. This gives an economy over counterboring of ten to one.

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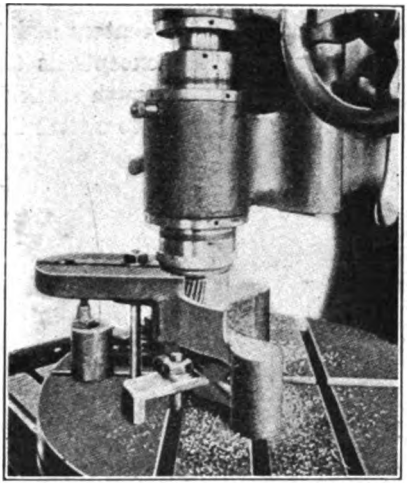

FIG. 1345*b*. — Segment Milling.

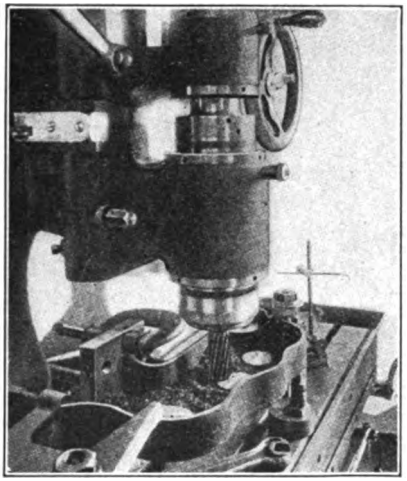

FIG. 1345*c*. — Spot Facing.

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1346. Hobbing a Worm Wheel. Fig. 1346 illustrates the method of hobbing a worm wheel after the teeth have been gashed. The gashing of the worm blank is accomplished by placing it on an arbor between the centers and treating it as if it was an ordinary gear, with the exceptions that such a gear cutter be selected as to leave just enough stock for the finishing cut with the hob; and it is necessary to swivel the table through

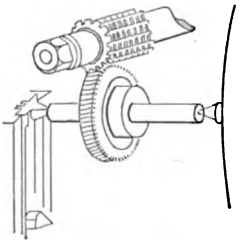

FIG. 1346*a*. — Hobbing a Worm Wheel.

an angle whose magnitude depends upon the pitch and diameter of the worm. Owing to the shape of the face of the worm gear it cannot be fed to the cutter in a manner similar to that used for spur-gear operations, but must be fed to the cutter to the desired depth, and then dropped and indexed for each succeeding cut. Swivel the table to the right for a right-handed worm

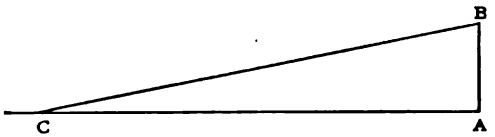

FIG. 1346*b*.

thread and to the left for the left-handed thread. For the final operation of hobbing, the carriage and table are brought back to zero. The determination of the angle through which the table is swiveled is as follows: Lay off the distance AB equal to the pitch and the distance AC at right angles to AB (Fig. 1346*b*). AC is the result obtained by multiplying the pitch diameter of the worm by 3.1416. Connect the points C and B with a straight line; then the angle ACB gives the number of degrees through which the table must be swiveled.

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1347. Cutting Bevel and Miter Gears. Fig. 1347*a* illustrates the method of setting for cutting bevel and miter gears. The blank is mounted on a suitable arbor held in the chuck or spindle; the spindle is then swung around in the head until the root line of the tooth is parallel with the table top. The proper cutter should now be selected, placed on the cutter arbor and brought central with the work. The following is a rule for determining the selection of a cutter for bevel gears. Divide the number of

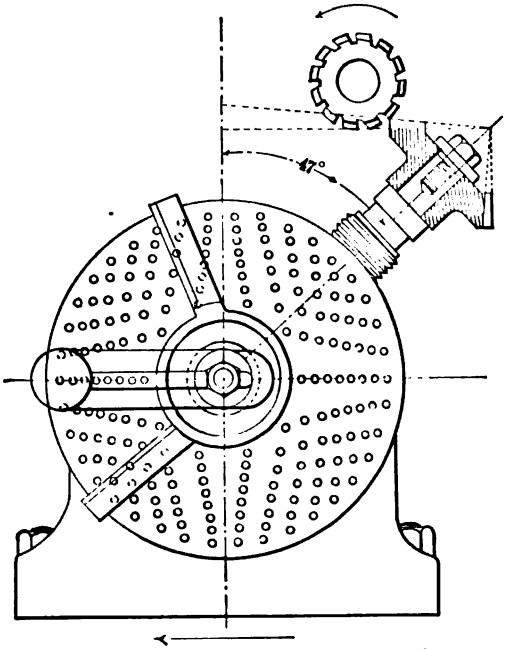

FIG. 1347*a*. — Cutting Bevel and Miter Gears.

teeth of the bevel gear by the natural cosine of the center angle (*y o z* in Fig. 1347*b*), this gives the number of teeth in the fictitious gear for which a standard cutter for this number of teeth is selected. When working from a drawing, twice the slant height of the back cone *y z* multiplied by the diametral pitch gives the number of teeth in the fictitious gear for which the cutter is to be selected. Below is outlined the ordinary method of procedure — using the above-mentioned rule for the selection of the cutter — when cutting bevel and miter gears with a single cutter; the

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teeth so cut are sufficiently exact for ordinary purposes, though being of but approximately correct outline. For a given pitch, in bevel and miter gears, the depth and width at the outer end of the tooth is the same as for spur gears. As the convergence of the teeth renders the inner end of the tooth portion narrower, the cutters for bevel gears must be thinner than for spur gears; hence the foregoing rule for selecting cutters of correct thickness.

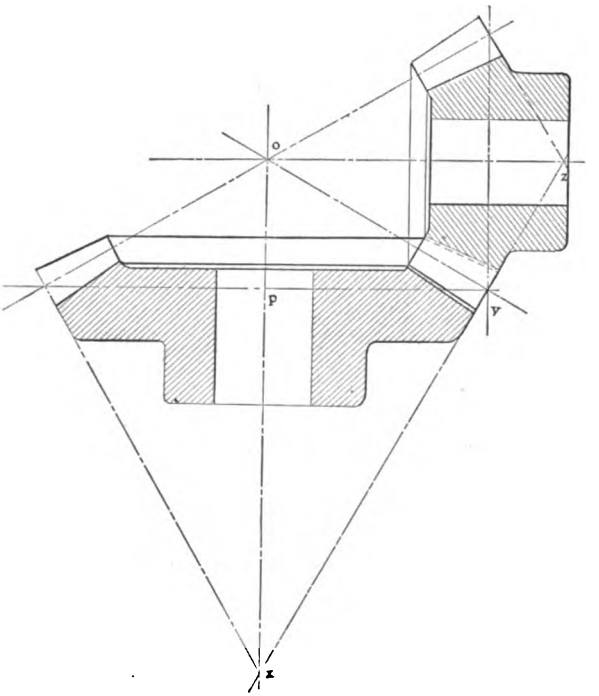

FIG. 1347*b*.

With the index pointer set for the proper number of teeth, two center cuts are taken; the blank is then moved off center a few thousandths of an inch (say $\frac{1}{10}$ the tooth thickness) and the index pointer advanced until the cutter will enter the small end of one of the central cuts. The object of this latter setting is to remove stock from the side of the tooth, taking more at the outer end than at the inner. To take the cut on the opposite side of the tooth, the blank is moved back double the amount it had

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been moved out and the pointer set back twice the number of holes it had been advanced. If, upon measuring the thickness of the tooth at the outside, it is found to be more than the quotient obtained by dividing the circumference of the pitch circle by twice the number of teeth, the blank must be set farther off center. It may be well to state that no empirical rule exists for these settings, and that the tooth must be measured after each trial setting is taken. Attention is called to an A. S. M. E. paper, December, 1896, in which Forrest R. Jones and Arthur L. Goddard relate some experimental investigations to find a graphical method of determining these operations. This paper was published in the *American Machinist* of January 21, 1897. However, after the proper setting for any particular gear is had, the center cut is unnecessary, as the tooth may be finished by the two side cuts. A record of the successful setting should always be kept for future reference. For a more complete description of the processes of cutting bevel gears the student is referred to the Brown & Sharpe Treatises on Gearing.

1348. Helical Grooving. Fig. 1348*a* and 1348*b* illustrate the method of cutting helical grooves such as those of twist drills or spiral milling cutters. In this operation it is necessary to impart to the work rotary motion as well as longitudinal; this is accomplished by connecting the lead screw with the dividing head spindle by means of change gears. A table of change gears for spiral milling is always furnished with the machine. The distance the helix (spiral) advances in one revolution is called the lead (pitch). The following data are requisite before work of this character may be undertaken: the lead or pitch of the spiral, the spiral angle, and the number of teeth or grooves to be cut. After the work is placed between the centers, the change-gear table is consulted and the change gears adjusted; the table is then swung through an angle equal to that of the spiral angle. Right-handed spirals require that the rotation of the dividing head spindle be right-handed and *vice versa;* a change in the direction of rotation being effected by inserting or omitting an idler-gear in the change-gear mechanism. In fluting twist drills it is necessary to elevate the point in order that the web between the flutes may be thicker toward the shank, as is the case in ordinary practice.

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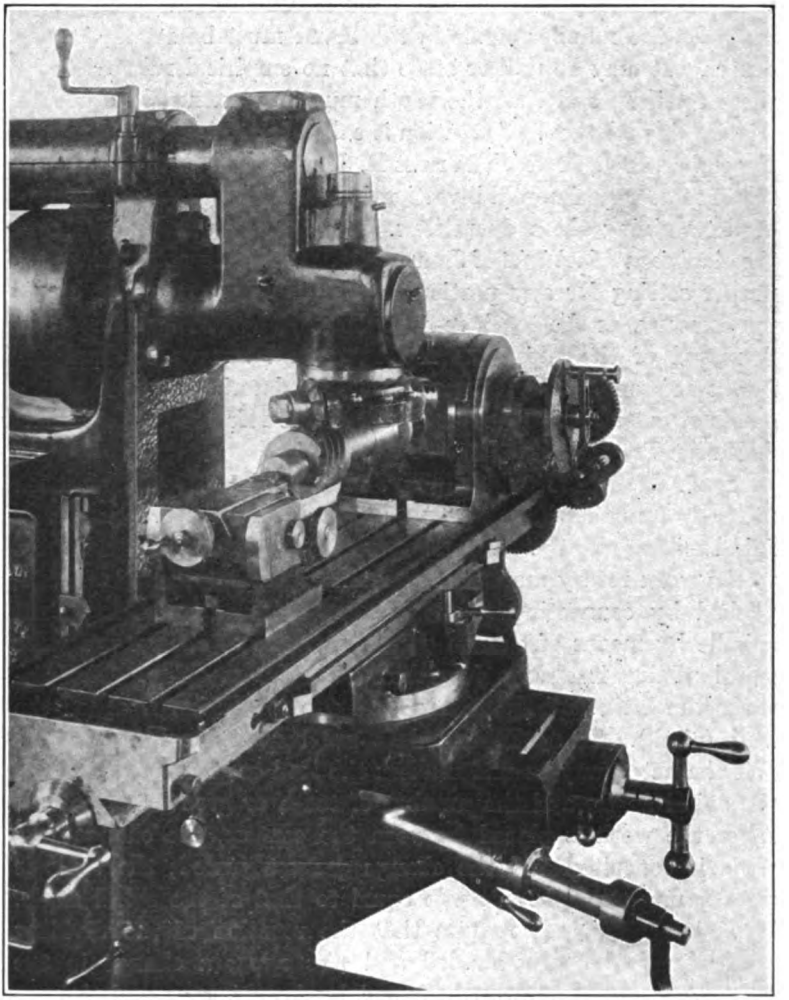

FIG. 1348*a*. — Milling a Spiral Cutter.

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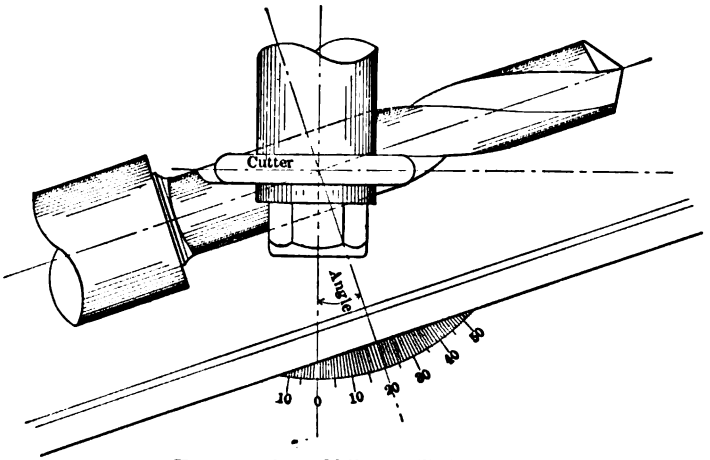

FIG. 1348*b*. — Milling a Twist Drill.

1349. Backing Off Drill Lands. Relieving the drill, *i.e.*, backing off the lands, is a distinctive and somewhat difficult operation; the method is illustrated in Fig. 1349. The table is swung through a small angle indicated by the line *BA;* this causes the end mill, the cutter used for this operation, to cut deeper at *C* than at *D*, thus producing the desired relief or clearance.

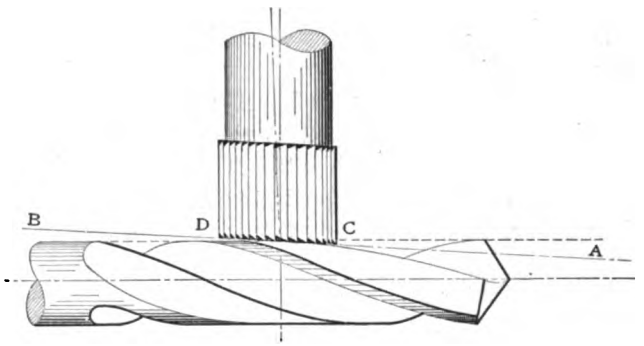

FIG. 1349. — Backing off Drill Lands.

GEARING

1351. The Sizing and Cutting of Gear Wheels. (From Brown & Sharpe's Catalogue.) The word "diameter" when applied to gears is always understood to mean the pitch diameter.

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Diametral pitch of the gear is the number of teeth to each inch of its pitch diameter. If a gear has 40 teeth and the pitch diameter is 4″, there are 10 teeth to each inch of the pitch diameter, and the diametral pitch is 10, or in other words the gear is 10 diametral pitch.

Circular pitch is the distance from the center of one tooth to the center of the next tooth, measured along the pitch circle. If the distance from the center of one tooth to the center of the next tooth, measured along the pitch circle, is ½″, the gear is ½″ circular pitch.

The diametral pitch given, to obtain the circular pitch, divide 3.1416 by the diametral pitch. If the diametral pitch is 4, divide 3.1416 by 4, and the quotient, .7854″, is the circular pitch.

The circular pitch given, to obtain the diametral pitch, divide 3.1416 by the circular pitch. If the circular pitch is 2″, divide 3.1416 by 2 and the quotient, 1.5708, is the diametral pitch.

The number of teeth and the diametral pitch given, to obtain the pitch diameter, divide the number of teeth by the diametral pitch. If the number of teeth is 40 and the diametral pitch 4, divide 40 by 4 and the quotient 10 is the pitch diameter.

The number of teeth and the diametral pitch given, to obtain the whole diameter or size of blank or gear, add 2 to the number of teeth and divide by the diametral pitch. If the number of teeth is 40 and the diametral pitch is 4, add 2 to the 40, making 42, and divide by 4; the quotient, 10½, is the whole diameter of the gear or blank.

The number of teeth and the diameter of the blank given, to obtain the diametral pitch, add 2 to the number of teeth, and divide by the diameter of the blank. If the number of teeth is 40, and the diameter of the blank is 10½″, add 2 to the number of teeth, making 42, and divide by 10½; the quotient, 4, is the diametral pitch.

The pitch diameter and the diametral pitch given, to obtain the number of teeth, multiply the pitch diameter by the diametral pitch. If the diameter of the pitch circle is 10″, and the diametral pitch is 4, multiply 10 by 4, and the product, 40, will be the number of teeth in the gear.

The whole diameter of the blank and diametral pitch given, to obtain the number of teeth in the gear, multiply the diameter by the diametral pitch and subtract 2. If the whole diameter

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is $10\frac{1}{2}''$ and the diametral pitch is 4, multiply $10\frac{1}{2}$ by 4, and the product 42, less 2, or 40, is the number of teeth.

The thickness of a tooth at the pitch line is found by dividing the circular pitch by 2, or by dividing 1.57 by the diametral pitch. If the circular pitch is 1.047″, or the diametral pitch is 3, divide 1.047 by 2, or 1.57 by 3, and the quotient, .523″, is the thickness of tooth.

The whole depth of a tooth is found by dividing 2.157 by the diametral pitch. If the diametral pitch of a gear is 6, the whole depth is 2.157 divided by 6, or .3595. The whole depth of a tooth is about $\frac{11}{16}$ or exactly .6866 of the circular pitch. If the circular pitch is 2, the whole depth of tooth is about $\frac{11}{16}$ of 2 inches or nearly $1\frac{3}{8}''$.

The distance between the centers of two gears is found by adding the number of teeth together, and dividing half the sum by the diametral pitch. If two gears have 50 and 30 teeth respectively, and are 5 pitch, add 50 and 30, making 80; divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8″, is the center distance.

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1352. Table of Gear Tooth Parts.

Threads or Teeth per In. Linear	Circular Pitch in Decimals	Circular Pitch in Inches and Fractions	Diametral Pitch	Thickness of Tooth on Pitch Line	Whole Depth of Tooth	Addendum and $\frac{1}{P}$ Height above the Pitch Line	Depth of Space Below Pitch Line
$\frac{1}{2}$	2.000	2	1.571	1.000	1.3732	.6366	.7366
$\frac{8}{15}$	1.875	$1\frac{7}{8}$	1.675	.9375	1.2874	.5968	.6906
$\frac{4}{7}$	1.750	$1\frac{3}{4}$	1.795	.8750	1.2016	.5570	.6445
$\frac{8}{15}$	1.625	$1\frac{5}{8}$	1.933	.8125	1.1158	.5173	.5985
$\frac{4}{8}$	1.500	$1\frac{1}{2}$	2.094	.7500	1.0299	.4775	.5525
$\frac{16}{28}$	1.437	$1\frac{7}{16}$	2.185	.7187	.9870	.4576	.5294
$\frac{8}{15}$	1.375	$1\frac{3}{8}$	2.285	.6875	.9441	.4377	.5064
$\frac{16}{21}$	1.312	$1\frac{5}{16}$	2.393	.6562	.9012	.4178	.4834
$\frac{4}{5}$	1.250	$1\frac{1}{4}$	2.513	.6250	.8583	.3979	.4604
$\frac{16}{19}$	1.187	$1\frac{3}{16}$	2.646	.5937	.8156	.3780	.4374
$\frac{8}{9}$	1.125	$1\frac{1}{8}$	2.792	.5625	.7724	.3581	.4143
$\frac{16}{17}$	1.063	$1\frac{1}{16}$	2.957	.5312	.7295	.3382	.3913
1	1.000	1	3.142	.5000	.6966	.3183	.3683
$1\frac{1}{15}$	.937	$\frac{15}{16}$	3.351	.4687	.6437	.2984	.3453
$1\frac{1}{7}$	.875	$\frac{7}{8}$	3.590	.4375	.6007	.2785	.3223
$1\frac{3}{13}$	.812	$\frac{13}{16}$	3.836	.4062	.5579	.2586	.2993
$1\frac{1}{3}$	.750	$\frac{3}{4}$	4.189	.3750	.5150	.2387	.2762
$1\frac{5}{11}$	.687	$\frac{11}{16}$	4.569	.3437	.4720	.2189	.2532
$1\frac{1}{2}$	.666	$\frac{2}{3}$	4.712	.3333	.4577	.2122	.2455
$1\frac{3}{5}$	.625	$\frac{5}{8}$	5.026	.3125	.4291	.1989	.2301
$1\frac{7}{9}$	.562	$\frac{9}{16}$	5.585	.2812	.3862	.1790	.2071
2	.500	$\frac{1}{2}$	6.283	.2500	.3433	.1592	.1842
$2\frac{2}{7}$	.437	$\frac{7}{16}$	7.181	.2187	.3003	.1393	.1611
$2\frac{1}{2}$	.400	$\frac{2}{5}$	7.854	.2000	.2746	.1273	.1473
$2\frac{2}{3}$	.375	$\frac{3}{8}$	8.377	.1875	.2575	.1194	.1381
3	.333	$\frac{1}{3}$	9.425	.1666	.2289	.1061	.1228
$3\frac{1}{3}$	.312	$\frac{5}{16}$	10.053	.1562	.2146	.0995	.1151
$3\frac{1}{2}$	.285	$\frac{2}{7}$	10.995	.1429	.1962	.0910	.1052
4	.250	$\frac{1}{4}$	12.566	.1250	.1716	.0796	.0921
$4\frac{1}{2}$	.222	$\frac{2}{9}$	14.137	.1111	.1526	.0707	.0818
5	.200	$\frac{1}{5}$	15.708	.1000	.1373	.0637	.0737
$5\frac{1}{3}$	.187	$\frac{3}{16}$	16.755	.0937	.1287	.0597	.0690
6	.166	$\frac{1}{6}$	18.850	.0833	.1144	.0531	.0614
7	.142	$\frac{1}{7}$	21.991	.0714	.0981	.0455	.0526
8	.125	$\frac{1}{8}$	25.133	.0625	.0858	.0398	.0460
9	.111	$\frac{1}{9}$	28.274	.0555	.0763	.0354	.0409
10	.100	$\frac{1}{10}$	31.416	.0500	.0687	.0318	.0368
16	.062	$\frac{1}{16}$	50.265	.0312	.0429	.0199	.0230

FIG. 1352.

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1353. Odontographics (Laying out gear teeth). — Grant's Cycloidal System. Taken from *Machinery* Data Sheets. The three-point odontograph, devised and calculated by Geo. B. Grant, is one of the best methods for laying out accurate gear teeth or the templates for gear teeth. The odontograph gives the centers and radii for drawing circular arcs which approximate the actual tooth curves.

To apply the odontograph to any particular case of cycloidal teeth, first draw the pitch, addendum (height above pitch line), root and clearance circles or lines, and space the pitch lines for the teeth in the usual way; then draw the line of flank centers at the tabular distance, outside of the pitch line, and the line of face centers inside of it. Take the face radius on the dividers and draw in all the face curves from centers on the line of face centers; then take the flank radius and draw all the flank curves from centers on the line of flank centers.

The table (Fig. 1354) gives the distances and radii if the pitch is either exactly one diametral or one inch circular, and for any other pitch multiply or divide as directed in the table.

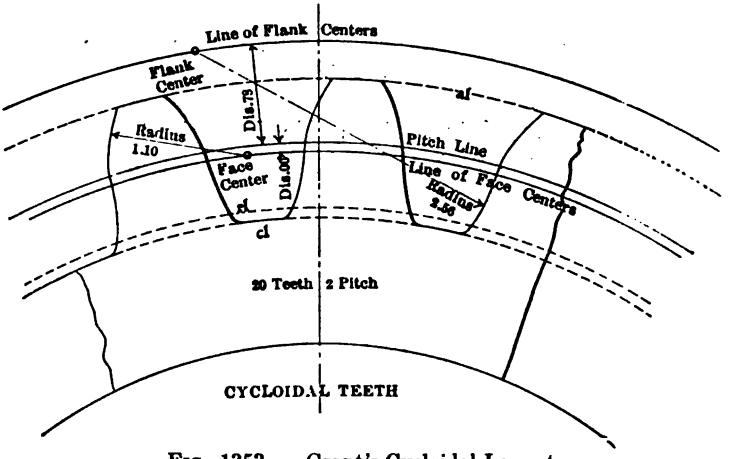

FIG. 1353. — Grant's Cycloidal Layout.

The odontograph may also be applied to laying out teeth for internal gears.

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1354. Table for Cycloidal Teeth.

Number of Teeth in the Gear		For One Diametral Pitch. For any other Pitch Divide by that Pitch				For One Inch Circular Pitch. For any other Pitch Multiply by that Pitch			
		Faces		Flanks		Faces		Flanks	
Exact	Intervals	Rad.	Dis.	Rad.	Dis.	Rad.	Dis.	Rad.	Dis.
10	10	1.99	.02	− 8.00	4.00	.62	.01	−2.55	1.27
11	11	2.00	.04	−11.05	6.50	.63	.01	−3.34	2.07
12	12	2.01	.06			.64	.02		
13½	13— 14	2.04	.07	15.10	9.43	.65	.02	4.80	3.00
15½	15— 16	2.10	.09	7.86	3.46	.67	.03	2.50	1.10
17½	17— 18	2.14	.11	6.13	2.20	.68	.04	1.95	.70
20	19— 21	2.20	.13	5.12	1.57	.70	.04	1.63	.50
23	22— 24	2.26	.15	4.50	1.13	.72	.05	1.43	.36
27	25— 29	2.33	.16	4.10	.96	.74	.05	1.30	.29
33	30— 36	2.40	.19	3.80	.72	.76	.06	1.20	.23
42	37— 48	2.48	.22	3.52	.63	.79	.07	1.12	.20
58	49— 72	2.60	.25	3.33	.54	.83	.08	1.06	.17
97	73—144	2.83	.28	3.14	.44	.90	.09	1.00	.14
290	145—300	2.92	.31	3.00	.38	.93	.10	.95	.13
	Rack	2.96	.34	2.96	.34	.94	.11	.94	.11

Fig. 1354.

1355. Grant's Involute System. To draft the tooth lay off the pitch, addendum, root and clearance lines, and space the pitch line for the teeth.

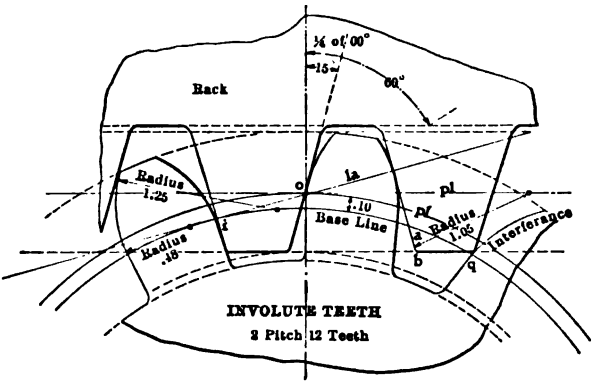

Fig. 1355. — Grant's Involute Layout.

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Draw the base line one sixtieth of the pitch diameter inside the pitch line.

Take the tabular face radius on the dividers, after multiplying or dividing it as required by the table (Fig. 1358), and draw in all the faces from the pitch line to the addendum line from centers on the base line.

Set the dividers to the tabular flank radius, and draw in all the flanks from the pitch line to the base line.

Draw straight radial flanks from the base line to the root line, and round into the clearance line.

1356. Laying Out the Involute Rack. Draw the sides of the rack tooth as straight lines inclined to the lines of centers at an angle of fifteen degrees, which is best found by quartering the angle at sixty degrees.

Draw the outer half of the face, one quarter of the whole length of the tooth, from a center on the pitch line, with a radius of

2.10 inches divided by the diametral pitch.
.67 inches multiplied by the circular pitch.

1357. Laying Out Internal Involute Gears. When the internal gear is to be drawn, the odontograph should be used as if the gear was an ordinary external gear; but care must be taken that the tooth of the gear is cut off to avoid interference. The point of the tooth may be left off altogether or rounded over to get the appearance of a long tooth. The pinion tooth need not be carried in to the usual root line, but may just clear the truncated tooth of the gear. The curves of the internal tooth and of its pinion may best be drawn in by points, for the odontographic corrected tooth is not as well adapted to the place as the true tooth, and no correction for interference is needed on the points of the pinion teeth or on the flanks of those of the gear.

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1358. Table for Involute Teeth.

Teeth	Divide by the Diametral Pitch		Multiply by the Circular Pitch	
	Face Radius	Flank Radius	Face Radius	Flank Radius
10	2.28	.69	.73	.22
11	2.40	.83	.76	.27
12	2.51	.96	.80	.31
13	2.62	1.09	.83	.34
14	2.72	1.22	.87	.39
15	2.82	1.34	.90	.43
16	2.92	1.46	.93	.47
17	3.02	1.58	.96	.50
18	3.12	1.69	.99	.54
19	3.22	1.79	1.03	.57
20	3.32	1.89	1.06	.60
21	3.41	1.98	1.09	.63
22	3.49	2.06	1.11	.66
23	3.57	2.15	1.13	.69
24	3.64	2.24	1.16	.71
25	3.71	2.33	1.18	.74
26	3.78	2.42	1.20	.77
27	3.85	2.50	1.23	.80
28	3.92	2.59	1.25	.82
29	3.99	2.67	1.27	.85
30	4.06	2.76	1.29	.88
31	4.13	2.85	1.31	.91
32	4.20	2.93	1.34	.93
33	4.27	3.01	1.36	.96
34	4.33	3.09	1.38	.99
35	4.39	3.16	1.39	1.01
36	4.45	3.23	1.41	1.03
37— 40	4.20		1.34	
41— 45	4.63		1.48	
46— 51	5.06		1.61	
52— 60	5.74		1.83	
61— 70	6.52		2.07	
71— 90	7.72		2.46	
91—120	9.78		3.11	
121—180	13.38		4.26	
181—360	21.62		6.88	

Fig. 1358.

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1359. Gearing Notes, Strength, Speed and Horse-power. In a paper before the Engineers' Club of Philadelphia, Wilfred Lewis develops the formula, $W = spfy$, for strength of gear teeth, under the following assumptions: (1) that the load transmitted, W, is well distributed across the tooth instead of at one corner; (2) that the whole load is taken by one tooth and that this tooth is considered as a beam loaded at one end. From a series of drawings of teeth of involute, cycloidal and radial flank systems, he determines the point of weakest cross-section of each and the ratio of the thickness at that section to the pitch. In the formula, $W = spfy$, W = load transmitted in pounds; s is the safe working stress of the material and is taken from the table, Fig. 1359*b*, which has been arranged to conform to the curve on the chart, Fig. 1359*a*; p = circular pitch in inches; f = face in inches; and y = a factor depending upon the form of the tooth and which may be calculated closely by the formulas,

For involute, 20° obliquity, $y = .154 - \frac{.912}{n}$

For involute, 15° and cycloidal, $y = .124 - \frac{.684}{n}$

For radial flank, $y = .075 - \frac{.276}{n}$

n being the number of teeth in the gear.

	Safe Working Stress, s, for Different Speeds							
Speed of Teeth in Ft. per Min. or less...	100	200	300	600	900	1,200	1,800	2,400
Cast Iron	7,000	6,000	5,350	4,000	3,250	2,700	2,000	1,650
Steel	17,500	15,000	13,375	10,000	8,125	6,750	5,000	4,125

FIG. 1359*b*.

Having determined the strength of the gear, we easily develop the following formula for the horse-power transmitted:

$$HP = \frac{Wv}{33{,}000},\ W = \frac{33{,}000\,HP}{v} = spfy,\ spfyv = 33{,}000\,HP$$

from which Mr. Lewis' general formula may take the form, $HP = \frac{spfyv}{33{,}000}$ in which v = the velocity in ft. per minute: since,

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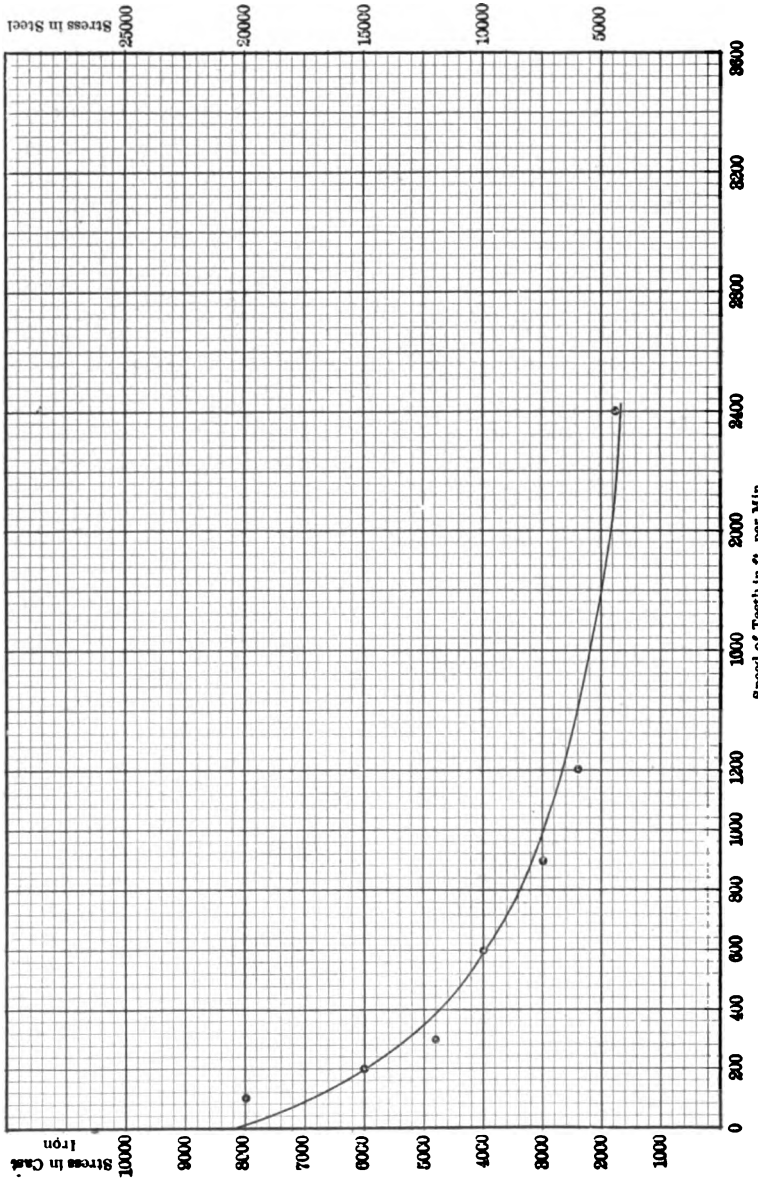

FIG. 1359a. — Plotting of Lewis' Values of "s" for Different Speeds.

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$v = \frac{\pi \text{ dia.} \times \text{rev. per min.}}{12}$, $v = .2618d \times$ rev. rep min. and we have,

$$HP = \frac{spfy \times .2618\, d \times \text{rev. per min.}}{33{,}000} = \frac{spfy \times \text{d} \times \text{rev. per min.}}{126{,}050}$$

$= .000{,}007{,}933\, d\ spfy \times$ rev. per min.

Arbors and Milling Cutters in General

1361. Arbors — Description and Use. The function of the milling machine arbor is to hold and rotate the milling cutter. The ordinary design has at one end a Brown & Sharpe taper similar in shape to a twist drill shank, and ground to fit a corresponding tapered hole in the spindle. That portion of the arbor

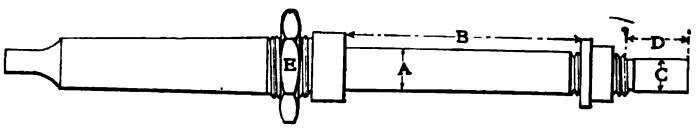

Fig. 1361. — Milling Machine Arbor.

projecting from the spindle and designed to carry the cutters is cylindrical, and carries a number of different width removable collars or washers, between which the cutter is clamped in any desired position. At either end of the straight portion, carrying the washers, is a threaded portion and nut; the nut nearest the tapered portion is used in removing the arbor from the spindle, the other nut for clamping the washers and cutter. Ordinarily the cutter is driven by the friction that exists between it and the washers, which is created by tightening the nut on the outer end of the arbor. A washer of ordinary writing paper, placed on either side of a cutter that persistently slips, will, in most cases, remedy this difficulty. For heavy work the cutter should be keyed to the arbor. If the thread on the outer end of the arbor be right-handed, a right-handed cutter should be used so that any tendency in the cutter to slip will tighten the nut.

1362. Shell Mill and Screw Arbors. Shell mill and screw arbors are designed for holding shell end milling cutters. By their use a saving in the cost of cutters is effected, for only that portion of the cutter designed for cutting need be of fine tool steel. This class of arbors and all stem or shanked cutters must be securely seated in the taper in the spindle.

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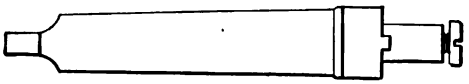

FIG. 1362*a*. — Arbor for Shell End Mills.

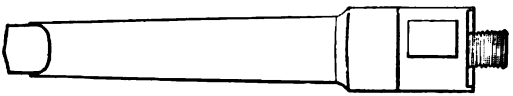

FIG. 1362*b*. — Milling Machine Screw Arbor.

1363. Collets. Collets, similar to drill collets, are used in the same manner and for the same purpose on milling machine arbors and stem or shanked cutters. Brown & Sharpe tapers ($\frac{1}{2}''$ per foot) are in general use for milling arbors and collets.

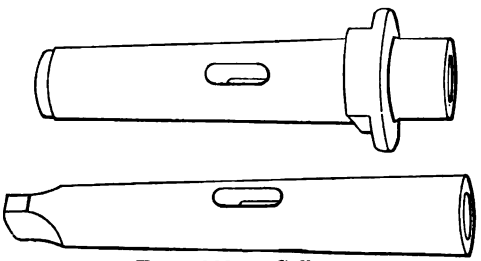

FIG. 1363. — Collets.

1364. Classification and Design of Cutters and Mills. Cutters are generally classed, according to the milling operations which they perform, into face or axial, side or radial, angular, end and form milling cutters; and again according to their construction, into solid, inserted tooth, stem or shanked, and end or shell end cutters. Cutters are also said to be right- or left-handed in accordance with their direction of rotation when cutting. This latter classification has reference in general to shanked or stem cutters, the majority of arbor-driven cutters being reversible. With the operator in front of and facing the machine, and the cutter adjusted, if, in order to cut, it must rotate in the direction opposite to the hands of a clock, it is a right-handed cutter, and *vice versa*.

The pitch of a cutter is the distance between two adjacent cutting edges. Ordinarily the front face of the milling cutter is cut radial; the top face is ground with from 3° to 5° clearance,

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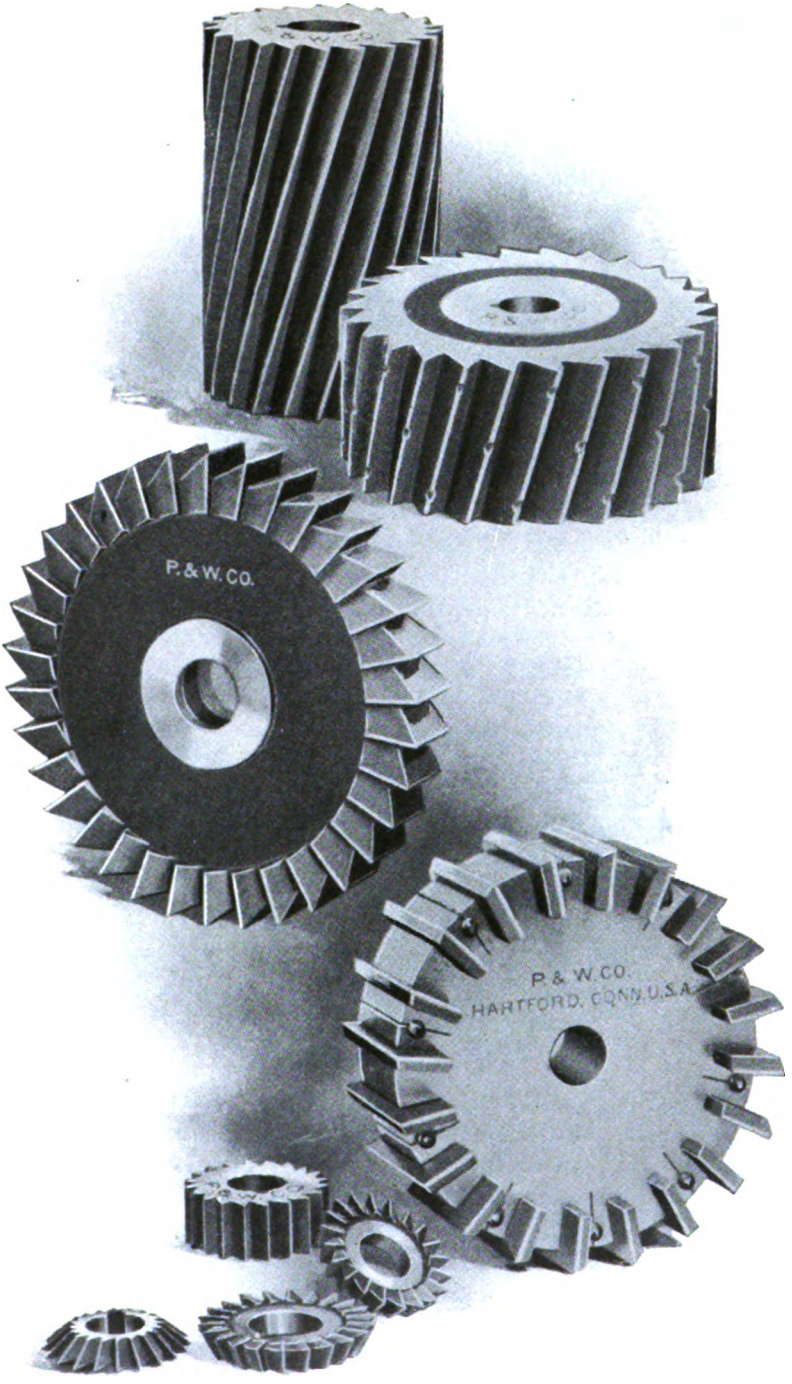

Fig. 1364. — A Page of Milling Cutters.

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or at an angle of 85° to 87° with the front face. The back face is usually cut at an angle of 52° with the front face.

1365. Care of Cutters. There are two general conditions which govern the efficient operation of a milling cutter: (1) It is absolutely essential that it be kept sharp. (2) That its cutting edges are equidistant from the axis of rotation. Never run a cutter backward; an endeavor to do so generally results in broken teeth. The disadvantages of dulness may be summed up as follows: poor work, more power required, the additional loss of temper in the cutter and elsewhere, and a general dissatisfaction to all concerned.

Milling Cutters — Specific

1371. Face Milling Cutters. Axial cutters that are intended for milling surfaces parallel to their axes of rotation are termed face-milling cutters. In general cutters of this class, under one inch in width, have straight cutting edges, *i.e.*, parallel to the axis of rotation. Wider cutters usually have helical cutting edges whose action may be contrasted as follows with that of those having straight cutting edges. With the straight-edged

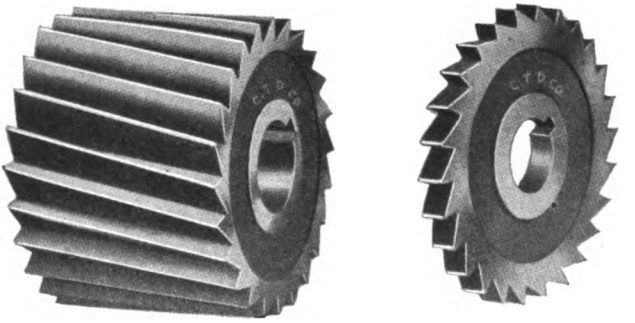

Fig. 1371. — Face Milling Cutters.

cutter each cutting edge strikes a distinct blow over the entire width, while with the spiral tooth cutter the action, commencing at one corner and proceeding across the surface of the work, is more that of shaving than chipping. Wide cutters usually have nicked teeth (cutting edges) for breaking up the chip; for this reason a cutter with nicked teeth requires less power to drive it, and consequently, with a given amount of power, heavier cuts may be taken with a nicked cutter.

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1372. Side Milling Cutters. Side or straddle milling cutters are designed for milling surfaces perpendicular to the axis of rotation of the cutter, and differ from the face mills in that they

FIG. 1372. — Side or Straddle Milling Cutter.

have cutting edges formed on their sides in addition to those on the periphery. With this class of cutter the work may be fed either against the face teeth or against the side teeth as desired.

1373. Angular Milling Cutters. Angular milling cutters are divided into single and double angle cutters according as they possess one or two cutting edges and are designed for milling surfaces at an angle to the axis of rotation of the cutter. If the angle included between the perpendicular to the axis of rotation and the inclined edge is a 45° or 60° angle, the cutter is designated

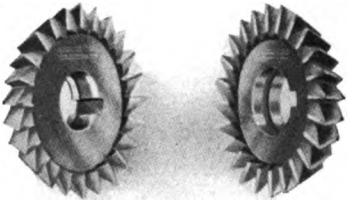

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FIG. 1373. — Angular Milling Cutter. No. 1 Right, and No. 2, Left Hand.

as a 45° or 60° cutter. If the angle on one side of the perpendicular of a double angle cutter be 12° and the angle on the other side be 40°, the cutter is designated as a 12°, 40° double-angle cutter; such a cutter is used for cutting the teeth grooves of a spiral (helical) cutter.

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1374. End Milling Cutters. The term end mill has reference in general to such stem or shanked cutters as are held directly in the spindle and used for end and slot milling. In construction they are a combination of the side and face milling cutters. The larger end mills are made hollow and are screwed or otherwise fastened to the taper shank; these are termed shell end mills.

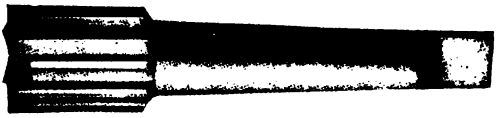

FIG. 1374. — Right-hand End Mill.

"T" slot cutters, as their name indicates, are used for cutting "T" slots and are shanked similar to end mills.

1375. Form Milling Cutters and Formed Cutters. Form milling cutters are designed for milling irregular or curved surfaces. The term *form cutter* is usually applied to such cutters as have cutting edges of irregular outline and teeth cut similar to those of an ordinary milling cutter. This class of cutters can rarely be ground without changing their profile. A form cutter may be a combination of several cutters as is the case with gang mills. *Formed cutters*, however, are form milling cutters so designed and backed off that they may be ground and still retain their original profile. Gear cutters and cutters for grooving taps, reamers and drills are classed as formed cutters.

1376. Fly Cutters. A cutter having a single cutting edge similar to that of a boring tool, ground to any desired profile, and inserted in a taper shank like that of an end mill, is the simplest of all form-milling cutters. Such a combination is called a fly cutter and is adapted to such work as the making of tools for screw machines, gears with odd pitch teeth, and such work as does not warrant the expense of a regular form cutter.

1377. Inserted Tooth Cutters. Owing to the expense of material and production, solid cutters are seldom made larger than 8″ in diameter or wider than 6″ in face. When larger cutters are desired they are generally built up, *i.e.*, having tool steel blades or teeth inserted and clamped in a body of some inexpensive material in such a manner as to admit of their being easily removed in case of injury or wear. There are several styles of inserted

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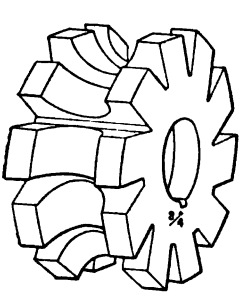
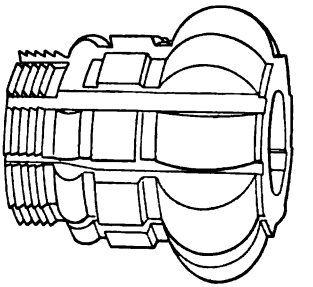
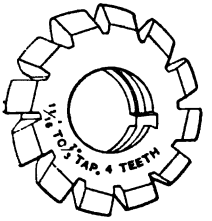


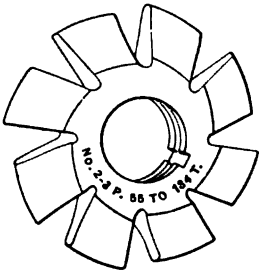
Concave and Convex Cutters for Milling Half Circles.



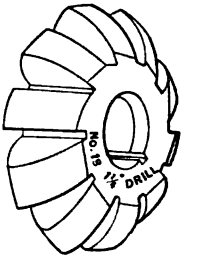
Formed Milling Cutter for Milling Parts of Machinery.



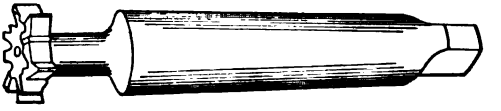
For Taps and Reamers.



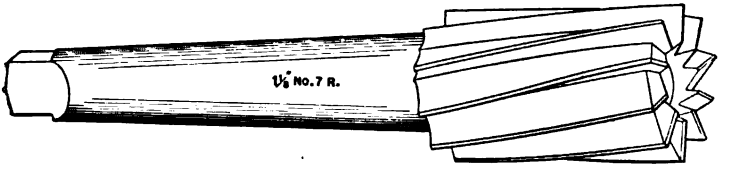
For Teeth in Gear-Wheels.



For Grooving Straight-Lipped Twist-Drills.



Right-Hand Cutter. T-Slot Cutter.



For End-Milling, Die-Sinking and Milling Slots.

FIG. 1375. — Formed and Form Milling Cutters.

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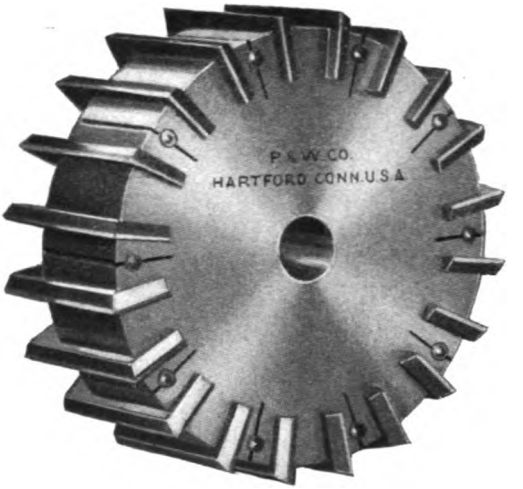

FIG. 1377. — Inserted Blade or Tooth Milling Cutter.

tooth, or built-up, cutters now on the market, and many are the designs and devices for holding the teeth or blades.

1378. Slitting Saws and Screw Slotters. Axial cutters whose width of face is less than $\frac{1}{4}''$ are termed either slitting saws or

FIG. 1378*a*. — Metal Slitting Saw or Cutter.

screw slotters, according to their construction and use. Slitting saws are ground hollow on the sides for clearance.

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FIG. 1378*b*. — Cutter for Key-seating and Slotting.

1379. Straddle and Gang Mills. When two side-milling cutters are placed on the arbor and separated by a washer, in such a manner that two opposite sides of a piece may be machined at

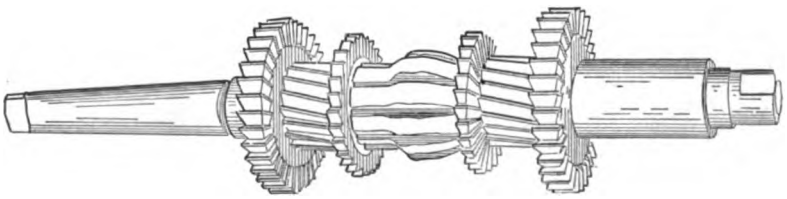

FIG. 1379. — A Gang Mill.

one operation, they are termed straddle mills. If, in the above arrangement, a face mill be used instead of the washer between the side mills, the combination is termed a gang mill.

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CHAPTER XIV

MISCELLANEOUS MACHINE TOOLS AND ACCESSORIES

Presses

1411. Classification. The two common classes of presses with which the machinist is familiar are *assembling* and *die presses.* Assembling presses are used for assembling press or forcing fits and, though generally hydraulic, are sometimes operated by hand or power; while presses using dies for punching and stamping sheet metal are termed die presses.

1412. Assembling Presses — Arbor — Hydraulic. An arbor press is a small hand assembling press, used chiefly for pressing arbors into the hubs of the various bored pieces to be turned.

In brief, the essential parts of the hydraulic assembling press are: a *hydraulic cylinder* containing the movable *ram,* which latter does the pressing by being forced outward; a sliding *head* against which the pressing is done; *tie bars* which hold the sliding head, cylinder and ram in their relative positions; a *hydraulic pump* for pumping the water into the cylinder; and a *base* with a *guideway* for supporting these details.

1413. Die Presses. Die presses, or punching and stamping presses, may be hand or power machines; the hand presses are usually "screw presses," while the power presses are generally presses with a reciprocatory ram. This latter class may be briefly described as having the following essential parts: A *base* or legs supporting the *bed* or *platen* and the operating mechanism; a *bolster* for holding the *die block; housings,* carrying the *guide* for the *ram* and the bearing for the crank shaft; a reciprocating *ram,* in the head end of which is fitted the *punch shank;* and the operating mechanism, consisting of a *crank shaft,* a *clutch* and a *heavy driving wheel.*

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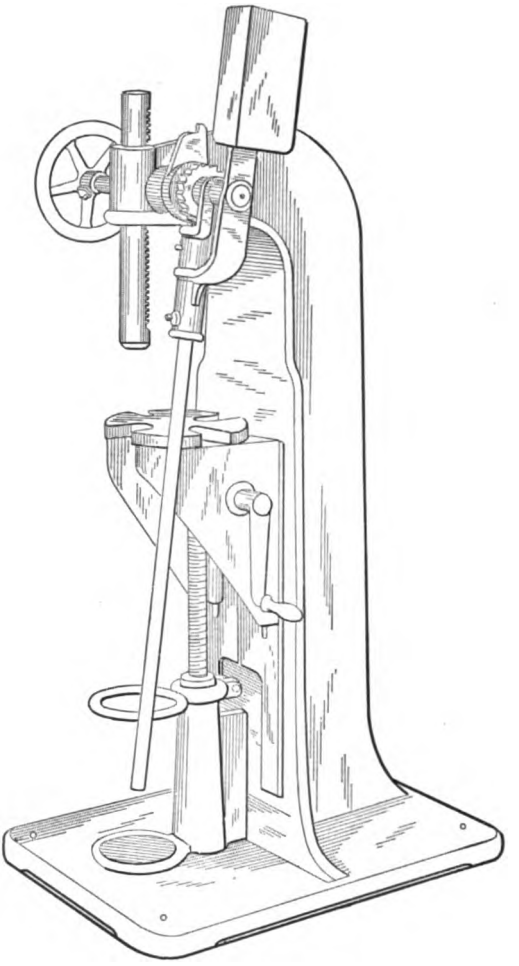

FIG. 1412*a*. — Greenerd Arbor Press.

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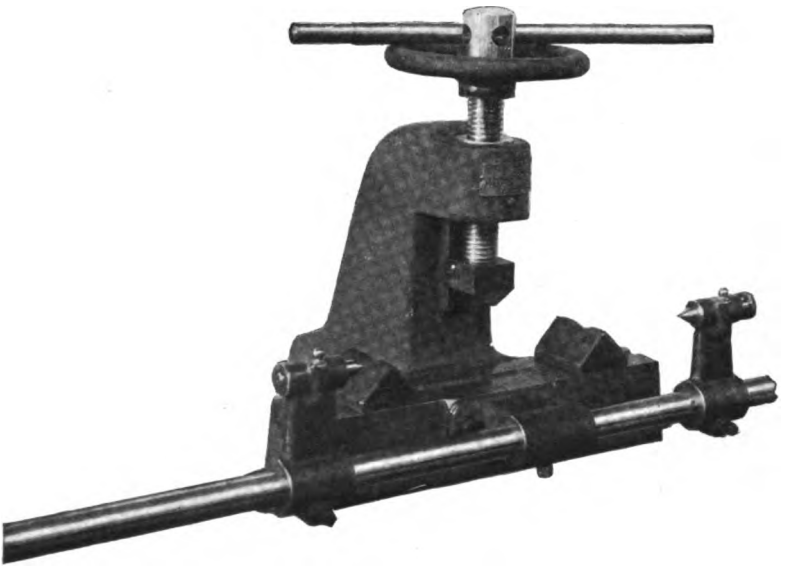

FIG. 1412*b*. — Springfield Bench Straightening Press.

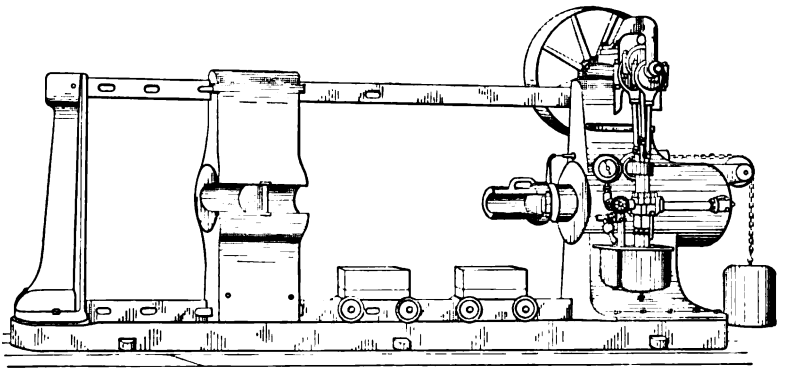

FIG. 1412*c*. — 200-Ton Hydraulic Assembling Press.

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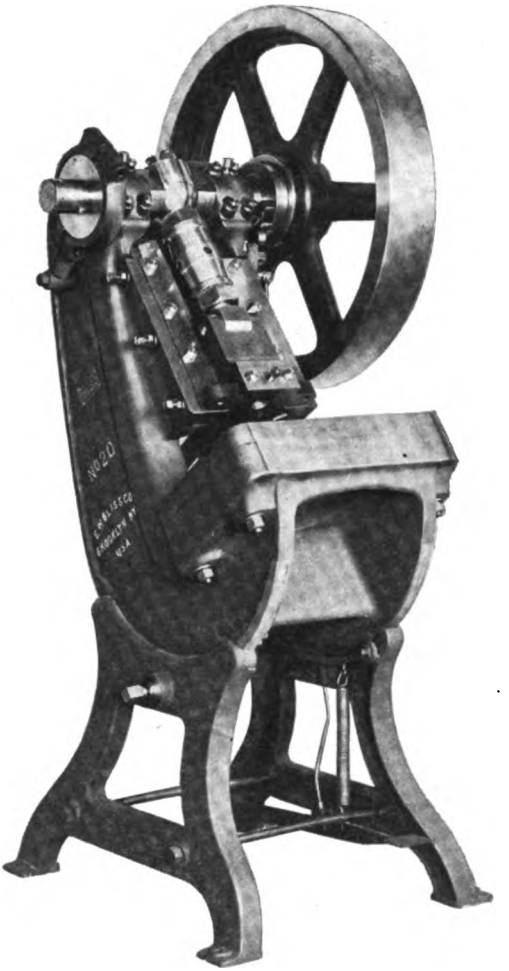

FIG. 1413. — Bliss Inclinable Power Die Press.

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Dies and Die Making

1421. Dies. Dies are made plain, multiple, gang and compound as the work seems to require, and some are very costly and complex in construction. Dies are made of a special tool steel and are hardened and tempered. The die block is given clearance of 1° to 2°, the clearance commencing about $\frac{1}{8}''$ below the cutting edge of the die. In general, the die block is first finished and then the punch block laid out from, and fitted to it. Die making requires much skill, time and patience, as much of the metal is removed largely by the hand processes of chipping and filing, broaching and grinding, and many a fine die has been ruined by cracking during the process of hardening.

1422. Die Making. Die making forms an important division of tool making and skilled die makers are well paid and in constant demand. The operations known as *bending, forming* — pressing sheet metal into a cavity of a simple form; *drawing* — a forming process of drawing the metal through rigid flat surfaces in order to prevent its wrinkling on the edges; *embossing* — a forming process which leaves some design in relief on the metal; and *curling* — the forming of a hollow cylindrical ring at the end of a piece, are all accomplished in presses by the use of various shaped dies and punches.

When used collectively, the term die refers to the *die block* and the punch; the essential parts of the die block being the hardened and tempered piece containing the opening or cavity, and termed the *block;* the *stripper plate* which strips the stock from the *punch;* the *gage pin* and *guide strip,* which hold the stock in its proper relation to the punch and die. The punch consists of the *punch block* of the desired shape, which does the shaping or cutting; the *collar* which takes the thrust; and the *shank,* by means of which it is held in the ram.

Turret Machines

1431. Turret Lathes. The turret lathe is essentially a manufacturing lathe and is used for the production of a large number of similar turned pieces. The characteristic feature of this lathe is the turret, designed to bring in rapid succession a number of varieties of tools, which act on the stock passed through the spindle and held in the chuck. The turret, carrying the turners,

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cutters and tools, is mounted on a slide which occupies the position of the tail-stock of the ordinary lathe; it is designed to revolve automatically, by the backward movement of the slide, on a vertical axis. After each tool has taken its cut, the slide is moved back; this backward movement automatically unlocks and revolves the turret and brings into position the tool which is to perform the next operation.

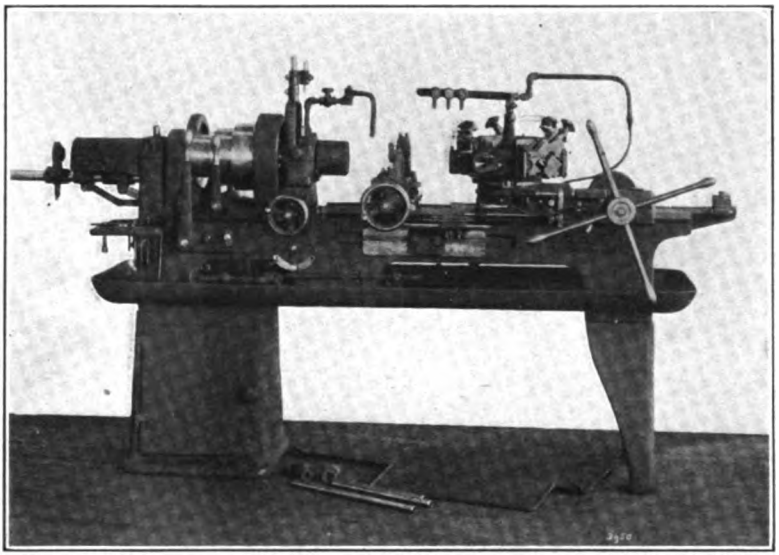

FIG. 1431. — Pratt & Whitney Turret Lathe.

Other important features of the turret lathe are the automatic chuck, which grips the bar of stock during the turning operations, and the cross-slide for cutting off operations.

1432. Box Tools and Turners. For turret lathe work box tools and turners — tools having a back rest which holds the work up to the cutters, thus securing the desired reduction in diameter — are used, though the hollow mill possesses many advantages for this class of lathe work. Screw cutting in the turret lathe is effected by the use of dies; during all cutting operations the work is flooded with lard oil.

It will be rightly inferred that the turret lathe must be "set up" for each kind of piece to be produced, and that, unless small, similar pieces are desired, the time consumed in the "set up"

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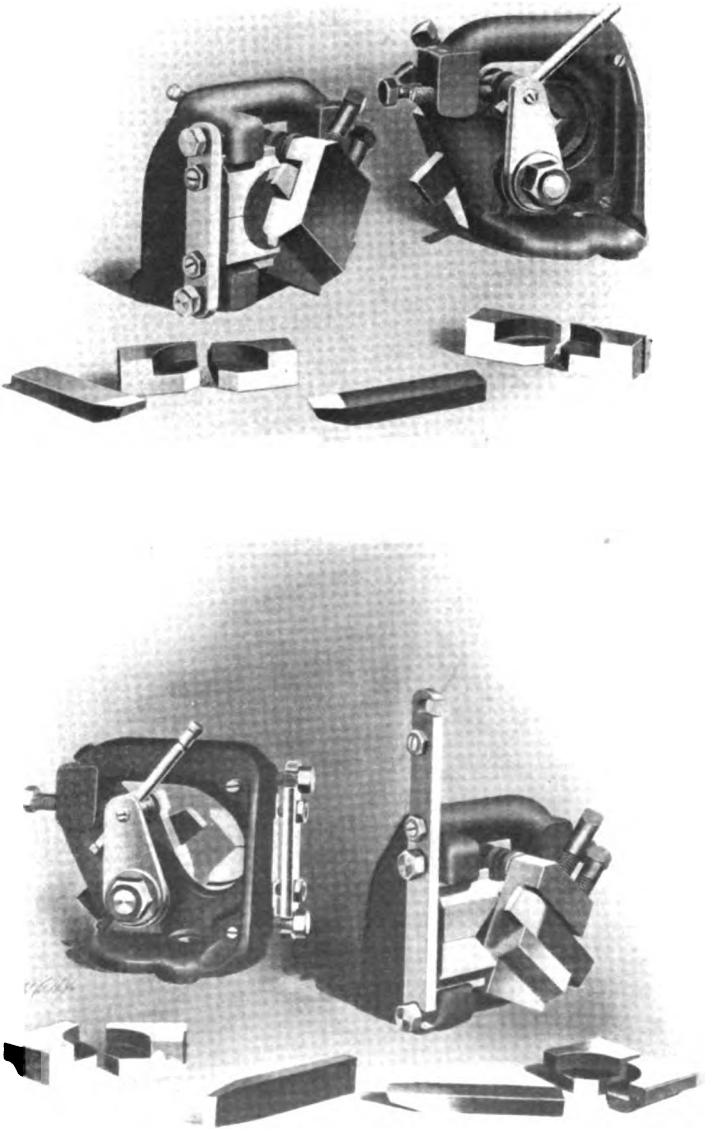

FIG. 1432*a*. — Hartness Regular Box Tools or Turners.

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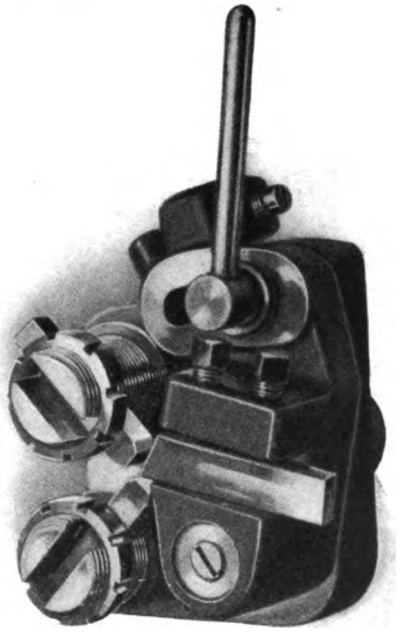

FIG. 1432*b*. — Pratt & Whitney Single Turner with Tangent Cutter.

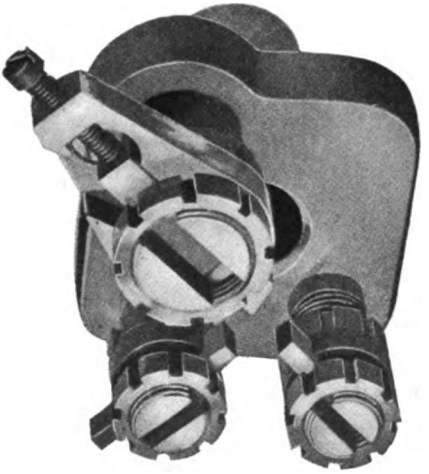

FIG. 1432*c*. — Pratt & Whitney Single Turner with Radial Cutter.

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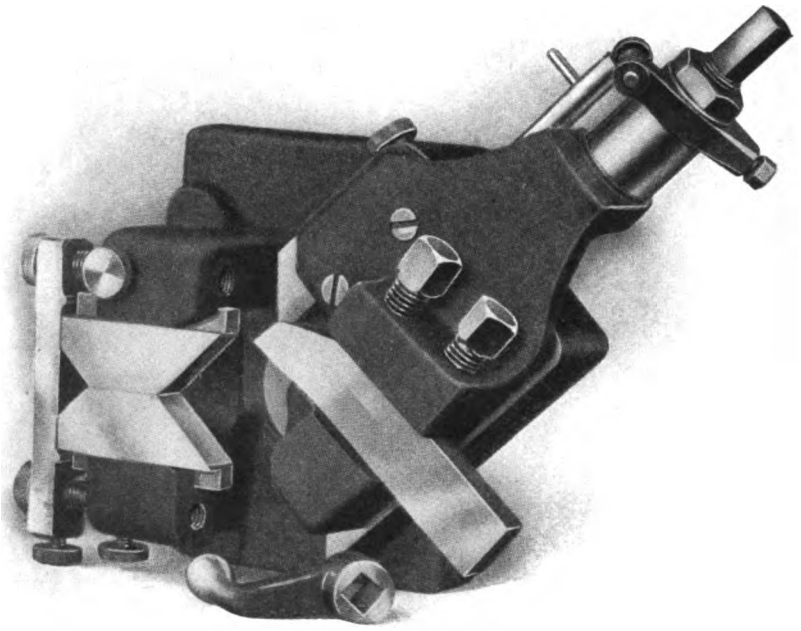

FIG. 1432*d*. — Pratt & Whitney Universal Turner.

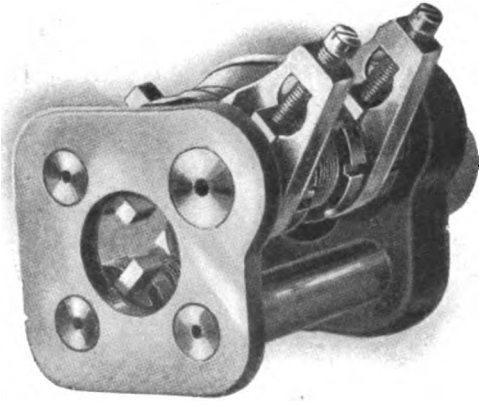

FIG. 1432*e*. — Pratt & Whitney Multiple Turner with Radial Cutters.

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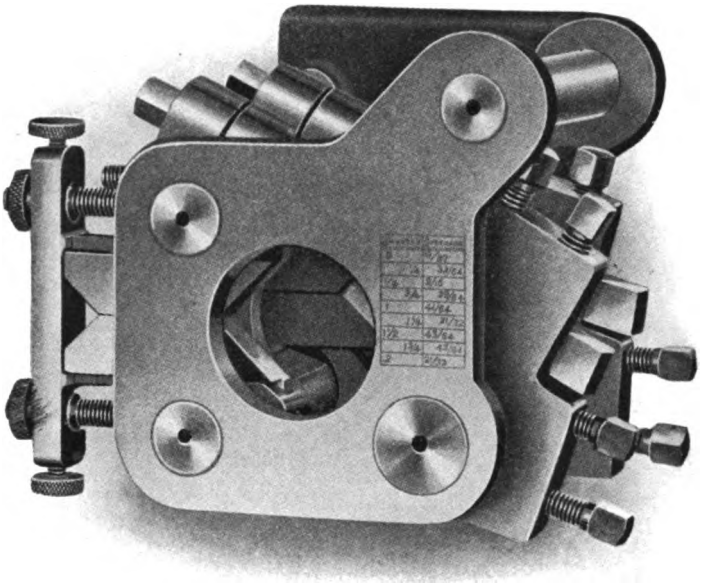

FIG. 1432*f*. — Pratt & Whitney Multiple Turner with Tangent Cutters.

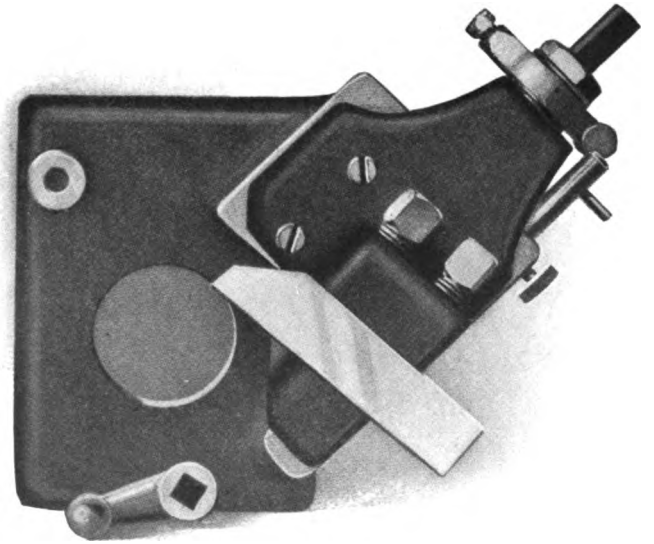

FIG. 1432*g*. — Pratt & Whitney Open Side Turner.

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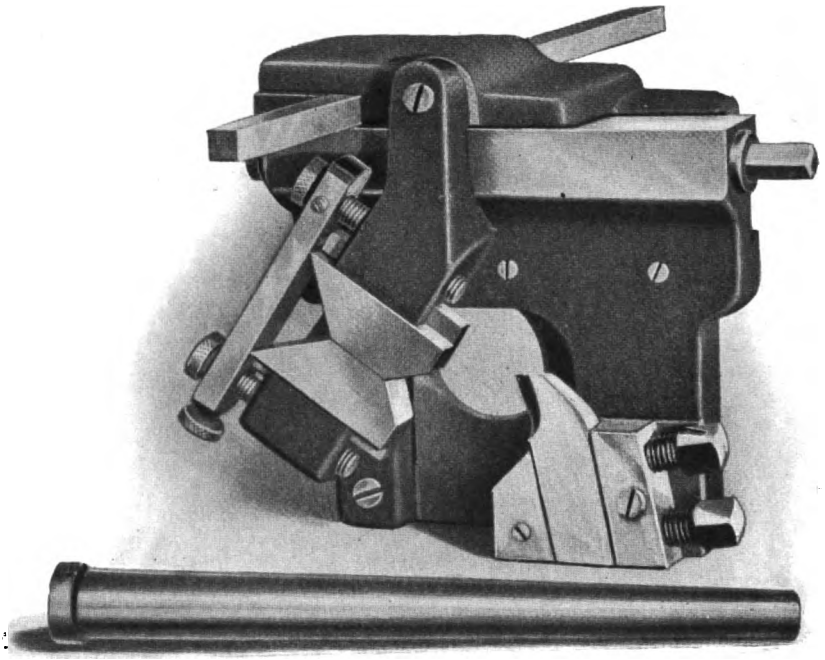

FIG. 1432*h*. — Pratt & Whitney Taper Turner with Leading Back Rest.

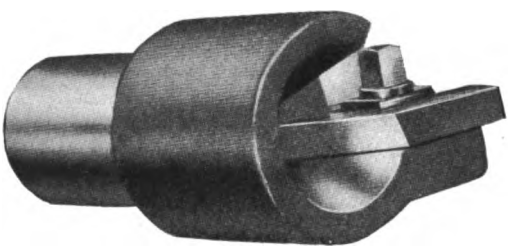

FIG. 1432*i*. — Pratt & Whitney Bell Mouth Pointing Tool.

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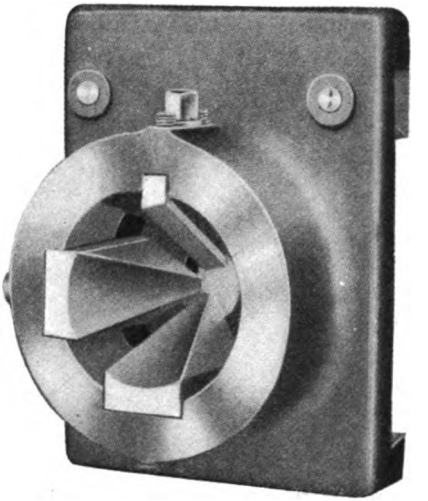

FIG. 1432*j*. — Pratt & Whitney Bell Mouth Pointing Tool.

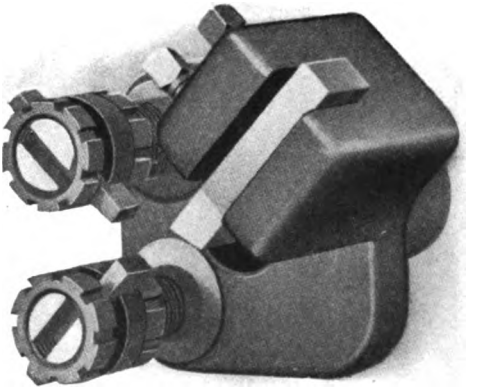

FIG. 1432*k*. — Pratt and Whitney End Forming and Pointing Tool.

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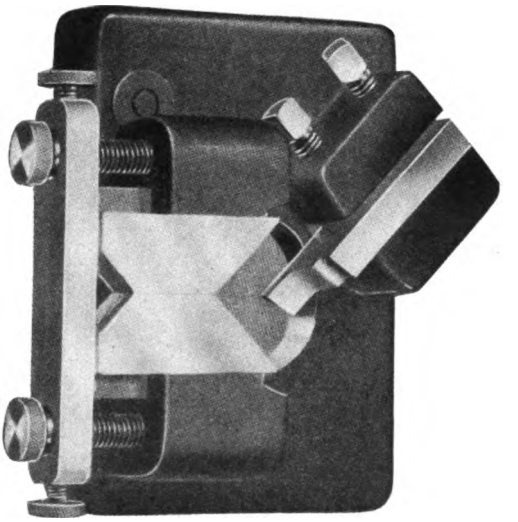

FIG. 1432*l*. — Pratt & Whitney End Forming and Pointing Tool with Forming Cutter.

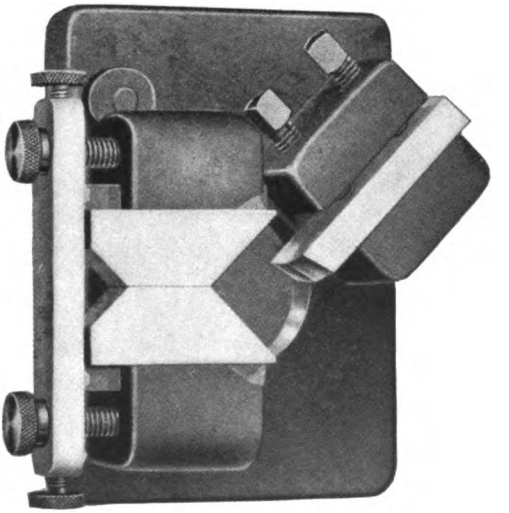

FIG. 1432*m*. — Pratt and Whitney End Forming and Pointing Tool.

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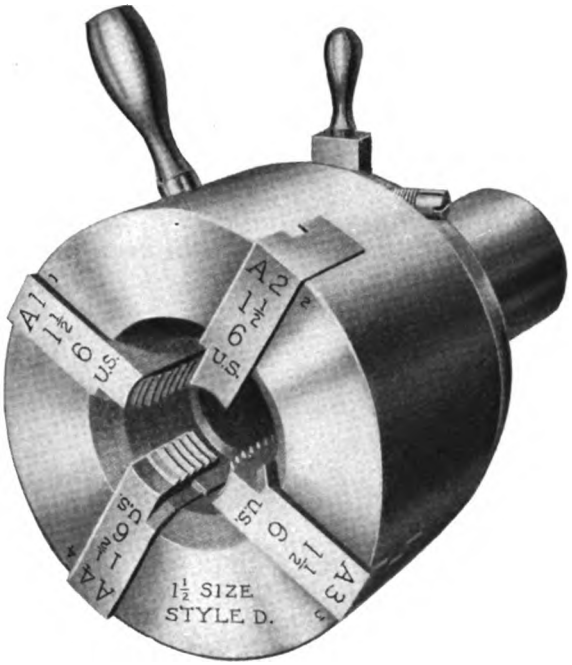

Fig. 1432*n*. — Pratt & Whitney Self-opening Die Head.

makes its use expensive. However, on repetitive work the actual time taken to produce a single piece is so little and the cuts so heavy as to excite the wonder and admiration of those who are unfamiliar with the operations of this epoch-making lathe.

Other well-known machine tools, that are modifications of the turret lathe, are: the Hartness flat turret lathe, the Gisholt lathe, screw machines, monitor and forming lathes.

1433. Screw Machines. The screw machine is essentially a turret lathe, the cutting operations of which are performed on the end of a bar passed through the spindle and chuck. Screw machines are either hand, automatic or multiple-spindle automatic, and like turret lathes must be "set up" for each kind of piece produced. With the automatic machines all the operations of feeding the stock, etc., are performed automatically through the media of levers and cams, it being desirable that there be with each new shape a specially designed or adjusted cam and a rearrangement of the tools. A good automatic screw machine

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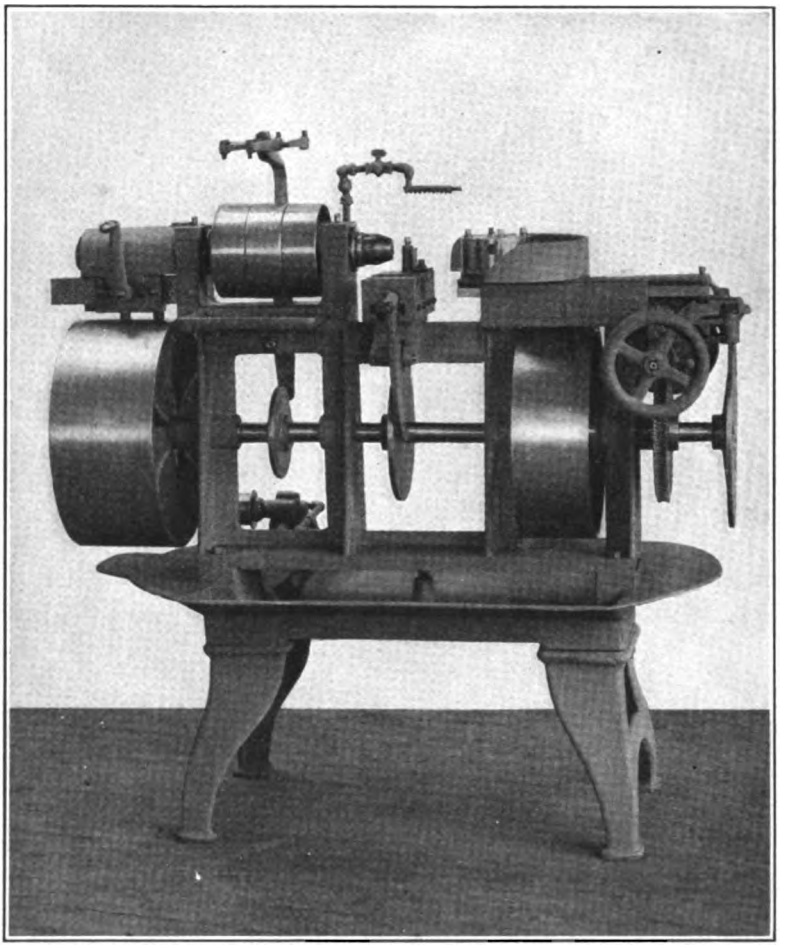

FIG. 1433. — Pratt & Whitney Automatic Screw Machine.

will produce as many as a thousand simple screws in an hour; and such work as binding posts, knurled thumb screws and similar shapes is considered its legitimate product.

1434. Monitor Lathes. Monitor lathes are used extensively in the manufacture of brass goods and for a great variety of other articles where several operations are required to finish the piece. This form of turret lathe is designed for finishing, from the rough castings, valve spindles and parts of globe and angle

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valves. The work is usually held in an automatic chuck, which may be operated by a lever without stopping the machine. Many monitor lathes are equipped with an attachment for chasing screw threads. The essential parts of this device are the master thread, hob or leader which fits over a stud on the head-stock; the chaser arm, carrying a half nut to fit this hob; and the chaser

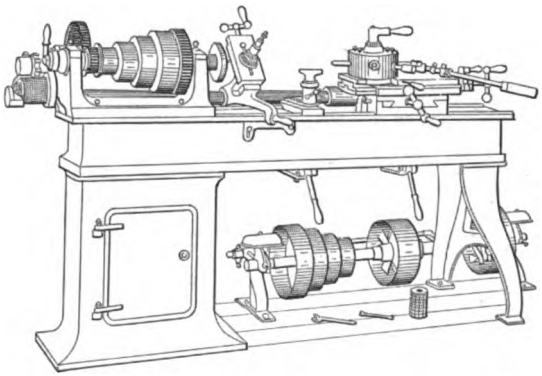

FIG. 1434. — American Monitor Lathe.

bar at the back of the lathe, to which this arm and the slide are attached. The operation of chasing threads, it will be seen, is a very simple one indeed.

1435. Forming Lathes. This type of turret lathe is used extensively for finishing brass and other soft metal castings, and is a form of the monitor lathe. It embodies a departure from the old system of turning irregular shapes and is extremely simple in operation, while the quality of work is such that, for a certain class of work, it is rapidly superseding other machines. The most characteristic feature of this machine is the forming tool and its slide. The forming tool is a tool having a cutting edge, the outline of which is similar to that of the piece to be turned. Fastened in the cross slide it is brought up to the work, and by means of a lever or screw the tool is fed across or under the piece which, with the one movement, it turns to its proper shape and diameter. Oil cups, cocks, hose nozzles and similar shapes are produced in this machine.

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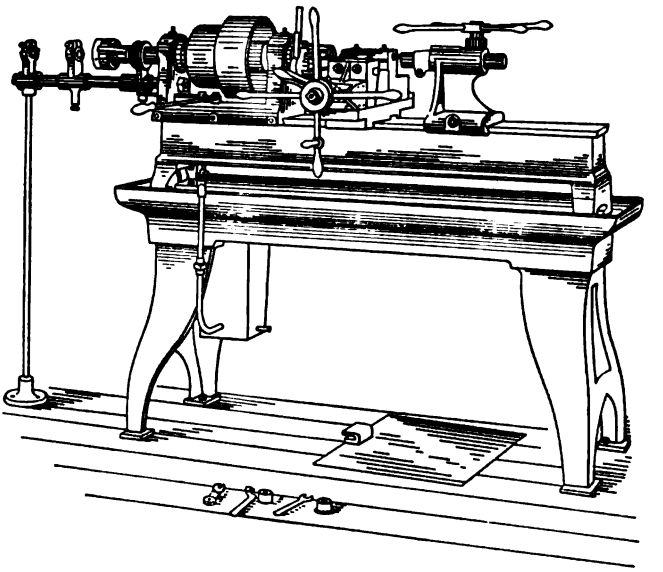

FIG. 1435*a*. — Garvin Forming Lathe.

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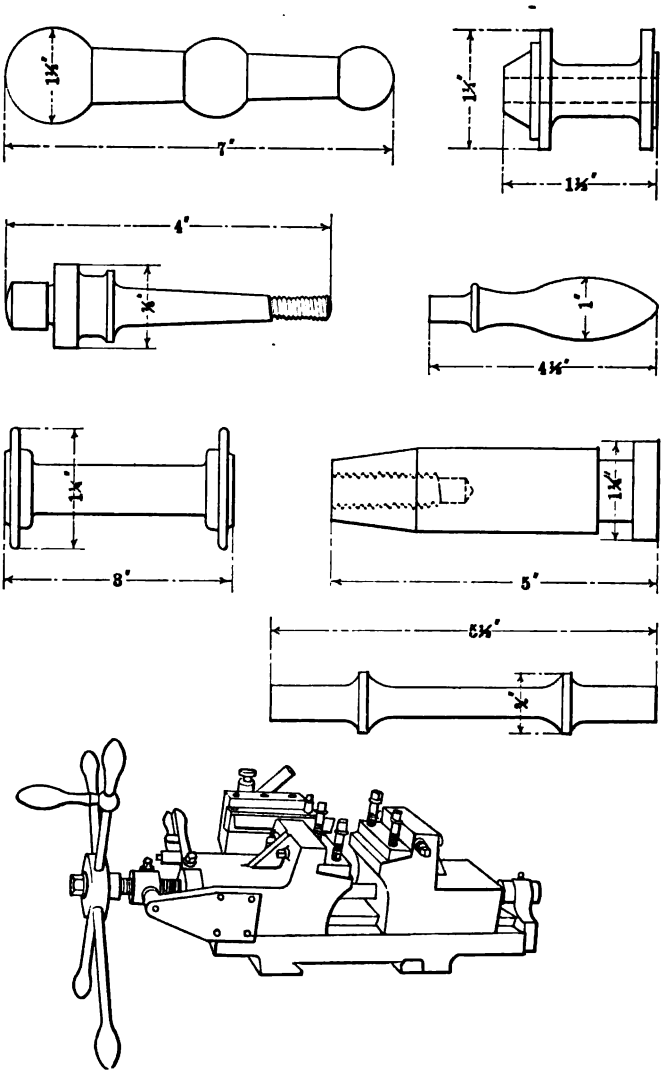

FIG. 1435*b*. — Forming Lathe Work and Slide.

JIGS

1441. Drilling and Filing Jigs. A jig is a device used in the manufacture of duplicate or interchangeable work to secure the accurate alignment of surfaces, parts or holes and the admeasurements of distances in such a manner as to facilitate the operation

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and eliminate the employment of skilled labor. Jigs may be divided, according to their use, into various classes, such as aligning, filing and drilling jigs. While jigs are used for lathe, planer and a variety of work, drill jigs — used also for reaming and tapping — are by far the most common type.

1442. Jig Characteristics and Design. Though existing in a variety of forms and shapes, the essential parts of a jig are: The *body*, on or in which the work is held and which supports the guides; the *guides* or *bushings* for the cutting tools; the *stops* which secure the alignment of the work in reference to these guides; the *clamping device* for holding the work; and a surface on which the jig rests, which insures the parallelism and alignment during the cutting operation. The guides are usually hardened and ground steel bushings which are inserted in the jig body, the insides of which are made to fit the drill, reamer or tap shank; their length is generally twice the diameter of the hole, the end receiving the drill being rounded inside and out. Clamp bushings are threaded on the outside and are used to assist in clamping the piece in the jig body.

In the design of a jig, according to John T. Usher, the spacing and the alignment of surfaces, holes, parts, etc., should be so combined as to expedite the process the jig is intended to facilitate, with, however, an entire absence of complication. The designer should always aim to make the jig in such a manner that it will require no effort whatever on the part of the operator to perform the work the jig has to be used upon. So successfully have these objects been accomplished in modern practice, that, by the use of jigs skilled labor has been entirely dispensed with in many instances, and in other instances, with skilled help the production has been increased to a surprising extent.

1443. Templets. Templets are used in the machine shops and also in the blacksmith and boiler shops to facilitate laying out operations. They are generally made of sheet metal and locate the centers and outlines which may be scribed from them. A templet should be so arranged as to be used for laying out as many surfaces and points as can be practically covered by a single templet and, when possible, it should be made with a view to using it as a test gage after the various operations have been performed.

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CHAPTER XV

SHOP PROCESSES AND KINKS

Methods of Working Iron and Steel

1511. Annealing — Ordinary — Dry — Water. Annealing may be defined as the process of restoring to normal condition iron and steel that have been unevenly worked, the uneven working producing internal strains and non-uniformity of structure.

Ordinary annealing may be done by heating the piece to a cherry red and allowing it to cool slowly to black heat. Cutting tools may be annealed in this manner before hardening.

Dry annealing is accomplished by heating the piece to a medium red and packing it in hot ashes, hot sand or powdered air-slacked lime, then allowing it to cool slowly.

Water annealing is accomplished by heating the steel to a dull red, allowing it to come almost to a black heat in hot ashes and then quenching it in water, brine or strong soap suds.

1512. Quenching Baths — Brine — Zinc Chloride Solution — Mercury. It is a well established fact that the hardening of steel depends primarily on the rapidity with which heat is extracted from it; and, secondarily on the temperature range through which it is cooled. Brine, since it has a much greater conductivity than water, will abstract heat much more quickly from articles quenched in it; thus a greater degree of hardness may be obtained by quenching from a given heat.

Steel may be made very hard indeed by quenching, from a cherry-red, in a neutral solution of zinc chloride.

Mercury, being a good conductor of heat, forms an excellent quenching bath.

1513. Tempering — Air, Oil, etc. As an introduction to tempering, the reader is referred to Sections 275, 276 and 277 where the subject is treated at some length.

Blades and thin pieces of steel are sometimes tempered by

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quenching them in a cold blast of air. The elasticity of Damascus blades is said to have been due to their having been air-tempered.

Oil is used to temper springs and tools having great elasticity; linseed is the best oil for this purpose. Quenching in oil does not chill the piece as does quenching in water, and the fumes from the oil surrounding it possess a higher temperature than the steam would have, with the result that the hardened tool is less brittle and more elastic than when treated otherwise.

Linseed oil ignites at 600°; consequently, if a hardened spring be covered with oil and the latter burned off, the resultant temper will be equivalent to that obtained from a temperature of nearly 600°.

Baths of air, lead, sand and oil heated to the proper temperature are often used for drawing the temper of hardened pieces. This is the scientific method of securing uniformity in the product for all pieces are cooled through the same temperature range, *i.e.*, from the critical point to the temperature of the bath.

1514. Case-hardening and Other Processes. For information relative to case-hardening and the other processes and treatments of iron and steel, the reader is referred to Chapter II, in which additional matter may be found. Case hardening is treated in Sec. 234.

Coloring Iron and Steel

1521. Preparatory Processes. In coloring iron or steel the following precautions are necessary to insure success:

The pieces to be colored should be finished and polished, the brilliancy of the color depending upon the finish.

The pieces should be scrupulously clean and free from oil.

If the color be an oxide, obtained by heating, the material in which the piece is placed should be heated uniformly throughout, and be just hot enough to char a dry, soft, pine stick.

Hardened pieces cannot be colored by a process of heating without having the temper drawn.

1522. Bluing. A simple method of bluing the finished or polished surfaces of iron or steel is to place, and allow them to remain, in hot sand, powdered charcoal or wood ashes until the desired color is obtained. Sand and wood ashes are used to

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obtain the light blues, the dark blues being obtained with powdered charcoal.

1523. Blacking. If a mixture of ten parts of potassium nitrate (saltpeter, KNO_3) and one part of black oxide of manganese (MnO_2) be substituted for the heating material in the above process, a deep, lustrous black will result.

1524. Chemically Obtained Browns and Blacks. This process consists of coating the pieces with a solution, by weight, made by dissolving one part of corrosive sublimate ($HgCl_2$, mercury bichloride) in a mixture consisting of sixteen parts of alcohol and sixteen parts of sweet niter ($NO.OC_2H_5$). The piece should be scrupulously clean and free from grease. The best results are obtained when the cleaning is effected by using first wet and then dry lime and taking care not to touch the articles with the fingers. After the solution has been applied with a sponge, the articles are allowed to remain from eight to forty-eight hours in a dark place, until a dry rust has formed upon them. A file card, free from grease, is used to remove this dry rust and to uncover the color; if the color is too light, the piece is again coated and the process repeated.

If a piece so treated be a dark brown, and be immersed for a few minutes in boiling water, then coated with oil while still dry and hot, the color will be changed to black. Gun barrels are colored by this, or modifications of this, process.

Cleaning Castings and Forgings

1531. Pickling. The surfaces of castings, drop forgings and many other materials may be cleaned of sand and other dirt by a process known as pickling. The castings are washed with, or placed in, a solution of one part commercial sulphuric acid (H_2SO_4) to from four to ten parts of water; after the acid has had time to act — ten to fifteen minutes — they are washed with clean water and cleaned with wire brushes or old files. Badly scaled wrought iron may be pickled in a solution of one part of hydrochloric acid (HCl) to ten parts of water. Brass castings are pickled in a solution of one part of nitric acid (HNO_3) to five parts of water. After pickling, the pieces should be thoroughly washed to remove all traces of the acid.

1532. Removing Grease and Dirt. Boiling or washing in hot soda forms a convenient and ready method for removing grease,

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grit and dirt from small machine parts. The solution is composed of one part sodium carbonate (Na_2CO_3, sal soda) to twenty parts of water.

1533. Use of Compressed Air. Where compressed air is had, a hose with a nozzle connected to the system will be found an excellent method for removing dirt and chips from holes and castings.

Soldering, Sweating, Brazing and Ferro-Fixing

1541. Terms Defined. Soldering, brazing or sweating is, according to the manner in which it is done, the process of uniting two pieces by covering their surfaces with a molten metal. Ferro-fixing defines the process of brazing castings and other metals by the use of a compound called Ferrofix.

1542. Soldering. Soft solder is a fusible alloy of lead and tin, while hard solder (spelter) is an alloy of copper and zinc or of copper, silver and zinc. The soldering iron or bit is generally used to apply and spread the metal. It consists of a pointed piece of copper, fastened to an iron rod which has a wooden handle. The joints to be soldered should be thoroughly cleaned, by scraping or filing, before the flux is applied, the kind of flux depending upon the kind of metal. Resin is used on tinned iron, commonly called tin; resin and tallow on lead; borax on iron; and salammoniac (ammonium chloride, NH_4Cl) on copper or brass. An excellent all-round flux is a fluid obtained by dissolving chips of zinc in a 50% solution of dilute hydrochloric acid. By adding to this solution one part, by weight, of ammonium chloride (sal-ammoniac) to eight parts of the fluid, this flux will answer for iron and steel.

1543. Sweating. When such pieces as half-boxes and bearings are united by solder for the operation of boring, the process is termed sweating. The surfaces to be united are cleaned, treated with a flux and tinned — heated until a greenish tinge appears, then coated with solder — after which the surfaces are pressed together and heated until the solder melts, when they are allowed to cool.

1544. Brazing. Brazing is accomplished by placing, between the pieces to be joined, a piece of spelter (hard solder) and fusing it while the pieces are held or clamped in position. The joint should be thoroughly cleaned and scraped before the flux is

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applied; the fusing of the spelter is accomplished, either by means of a blow-pipe, or by red-hot tongs which also clamp the pieces in position.

1545. Ferro-fixing. The process of brazing cast iron, long considered impossible, is now rendered commercially possible by the use of Ferrofix, a brazing compound invented by a German named Pich. Not only is this compound available for brazing broken cast iron, making it, it is claimed, stronger than new, but Mr. Pich has also succeeded in brazing broken wrought and malleable iron; cast iron to steel; wrought iron to cast; malleable iron to steel; and brass to each of these. The novelty of this process is entirely in the use of a coating of Ferrofix, applied to the surfaces to be united. The rest of the operation is performed in essentially the same manner as are the ordinary processes of brazing and sweating which have been briefly described.

Miscellaneous Kinks

1551. Forging Square Holes. A square hole may be easily forged in the end of a bar by first drilling into it a hole whose circumference equals the perimeter of the square desired and, after heating, hammering the piece until the hole is square.

1552. Dividing in the Lathe. This may be accomplished by using the teeth in the driving gear as a makeshift for the holes in an index plate.

1553. Rust Joints. An excellent mixture for filling up cracks or blow-holes in castings, or for cementing iron joints, is composed of one part, by weight, of salammoniac (NH_4Cl) to forty or sixty parts of cast-iron borings, together with enough water to form a thick paste; this is rammed into the joint and allowed to set.

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CHAPTER XVI

MECHANICS

Fundamental Principles

1611. Work. That we may not become confused in our terms, it is necessary to have a clear conception of the fundamental mechanical principles and definitions.

The common unit of work is the foot-pound, which may be defined as that amount of work performed when a weight of one pound is raised a height of one foot. The unit adopted by physicists is the erg, which is the amount of work done by a force of one dyne acting through the distance of one centimeter. The following relation or equation is one of the fundamental ones. Force $\times$ the distance through which it acts, always equals the resistance $\times$ the distance through which it is made to act; that is, $FD = rd$. Here we see that in the performance of work force and motion are of equal importance; and that a given amount of work may either be performed by a large force with slight movement or a small force with great movement. As an example, our idea of a 1500 horse-power engine is a machine of great size; however, it is not uncommon for the two small engines of our compound locomotives to develop this amount of power.

1612. Power. Power is the rate of doing work and is a product whose factors are space, time and force. A complete idea of the power of a prime mover, such as the steam engine, being formed when we say that it performs so many foot-pounds of work in one minute. Watt, in his anxiety to have his engines develop their rated capacity, took as the value of the horse-power a quantity nearly double what the average horse can develop while walking — 17,600 foot-pounds per minute — selecting the value 33,000 foot-pounds per minute. This unit of power is the one in common use in steam engineering. The unit of electrical power is the watt or kilowatt (one thousand watts), 746 watts being equivalent to one horse-power.

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Heat

1621. Theory. Heat is generally considered to be molecular kinetic energy, or rather the kinetic energy of ultimate particles of matter. That is, that energy which is due to the motions of the ultimate particles of the body under consideration, as distinguished from the term "molar kinetic energy," which is kinetic energy due to the motion of the body as a whole, independent of the individual relative motions of its component particles.

The particles composing a body do not come into this condition of motion spontaneously: such energy may come from some source outside the body, or it may be received by the particles on account of some chemical change taking place within the body itself. In any case, however, the particles must receive the energy from some source outside themselves. A rise of temperature is the usual manifestation which takes place from such a transference or transformation of energy, and a definite relation exists between the work (Force $\times$ Distance or $\frac{1}{2}$ Mass $\times$ Velocity^2) which disappears and the temperature rise which ensues in any given body.

1622. Relation between Heat and Work. Count Rumford was among the first to conceive the idea that heat is a mode of motion and is produced by the expenditure of work; basing this theory upon his observation of the large amount of heat produced in the process of boring cannons. It is a fact that in most cases energy expended in friction is entirely converted into heat. Tyndall's experiment of producing steam — the steam blowing a cork from the end of a tube — directly from the heat of friction illustrates the truth of this statement and exhibits the transference of the work of friction into heat energy, and of the heat energy in the steam into the work of motion in the cork.

In 1849 Dr. Joule devised an apparatus by which he was able to determine that the same relation always exists between a unit of work and a unit of heat. This was called the mechanical equivalent of heat; the unit of heat in the British system of units being that quantity required to raise the temperature of one pound of water one degree F. at the temperature of maximum density which is 39.2° F. or 4° C. The foot-pound previously defined as the unit of work is that amount necessary to raise one pound weight Avoirdupois vertically one foot. This mechanical equiv-

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alent of heat Joule determined to be 772.6 foot-pounds, while Professor Rowland's more exhaustive researches showed it to be 778 foot-pounds.

1623. An Experiment in Thermodynamics. Let us now consider the processes in the following experiment: The apparatus consists of a cylinder with a tightly fitting weightless, frictionless piston, and some method of heating the cylinder. A pound of water at 32° F. is placed in the cylinder underneath the piston. The first effect of the application of heat is to raise the temperature of the water which expands inappreciably. Beginning with the boiling of the water, the second effect is that of the formation of steam which forces the piston out. At the instant evaporation is complete as well as during all the time it is going on the cylinder is said to contain saturated steam; that is, steam which contains just exactly enough heat to maintain it in the gaseous form, and no more. The continued application of heat after evaporation has been completed results in the moving of the piston still farther, and the steam in the cylinder which has become considerably hotter — that is, contains more heat than is necessary to keep it in the gaseous form — is said to be superheated.

At the instant when all the water has been changed to steam, the piston will have been moved such a distance in the cylinder as will indicate that the volume of steam has increased 1646 times that of the water.

If we were to measure the number of heat units applied at the instant when the last drop of water was evaporated, we would discover that 180.9° were used to heat the water and 965.7° to effect a molecular change from water to steam, making the total heat units of steam at 212° to be 1146.6. If now we should arrange a table (Fig. 1623) setting down therein additional heat in pounds of steam at certain pressures and the differences, we would discover that with small additions of heat the pressure rises rapidly.

Absolute Pressure	Total Heat Units Above 32 Deg.	Additional Heat Units per Pound of Steam	Differences
14.7 Lbs.	1146.6		
25 "	1155.1	8.5	
75 "	1175.7	29.1	20.6
125 "	1186.9	40.3	11.2
175 "	1194.9	48.4	8.1
225 "	1201.4	54.8	6.4

FIG. 1623.

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From the above table we are impressed with the facts: (1) That so small a portion of the heat is converted into useful work and (2) that so marked an increase in pressure occurs by the addition of a small number of heat units. We then conclude this to be a wasteful method of using steam. Experience has proved that any method in which the steam follows the piston at full pressure during the entire stroke is wasteful. This led to the invention of various devices for cutting off the steam at some point before the completion of the stroke. It is sufficiently exact for our purpose to say that if a given quantity of steam be expanded to twice its volume, its pressure will be one half; if to three times its volume, its pressure will be one third.

Power Graphs and Computations

1631. The Indicator Card. On a graph representing pressures and volumes, the expansion curve will be an hyperbola and the area of the graph will represent the amount of work done. If steam be cut off at some portion of the stroke, the pressure upon the piston, it will be seen, is far from uniform and the speed of the piston is variable. In our computations of the work performed it will be necessary, then, to use average pressures and speeds; average pressures and speeds being those which produce the same total effect as variable ones.

In the following graph (Fig. 1631), where FD represents length of stroke and FA maximum pressure, the steam is cut off at one quarter of the stroke and expands to a minimum pressure of DC.

The area then of the graph may be taken as being proportional to the total work done by the steam. It is apparent that the economy of using expanding steam is great, as a glance reveals the area $BCDE$ to exceed that of $ABEF$. If the area of $ABEF$ be 1, it can be proven that the area of $BCDE$ equals the hyperbolic logarithm of the ratio of expansion. The ratio in this instance is 4; the hyperbolic logarithm for 4 is 1.386, so that the total area of the figure representing the total work done by the steam is 2.386. If we had allowed the steam to follow the piston during the entire stroke, the area of the graph would have been 4, but four times the amount of steam would have been used.

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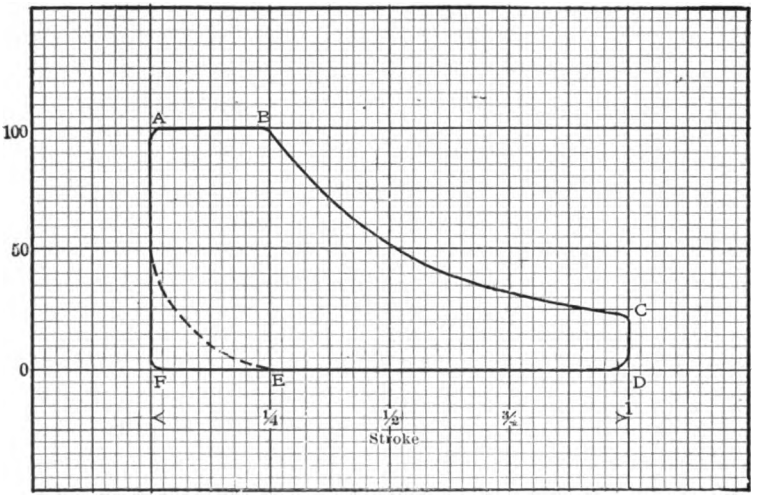

FIG. 1631. — Indicator Card.

1632. Power and Steam Computations. A computation of the steam used in each of the two instances will serve to illustrate the economy in another way. Let the area of the piston be 200 square inches, the revolutions 60 per minute, and the length of stroke 2 feet (two strokes always per revolution); then the foot-pounds of work developed per minute for the case when following full stroke are

Sq. in. Lbs. Ft. Revolutions Foot-pounds
$(200) \times (100) \times (4) \times (60)$ equals 4,800,000: the horse power being the foot-pounds divided by 33,000 or $\frac{4,800,000}{33,000}$ equals 145.4 horse-power.

The number of cubic feet of steam used per hour is

Sq. Ft. Feet Revolutions Minutes
$\frac{(200)}{(144)} \times (4) \times (60) \times (60)$ equals 20,000 cubic feet.

The weight of a cubic foot of steam at 100 pounds absolute is 0.23 pounds and the steam consumed per hour is 0.23 x 20,000 or 4600 pounds. The steam used per horse-power per hour is $\frac{4600}{145.4}$ equals 31.5 pounds of steam. Computing the steam used when cutting off at ¼ the stroke, we have: the average height of

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the figure or mean effective pressure $\frac{2.386}{4}$ equals .596 of the height or pressure due to 100 pounds. The average pressure is $100 \times .596$ equals 59.6 pounds. The work equals $200 \times 59.6 \times 4 \times 60$ equals 2,860,800 foot-pounds. $\frac{2,860,800}{33,000}$ equals 86.6, the horse-power. The steam used per hour equals $\frac{1}{4}$ quantity in first case or 1150 pounds; hence the quantity per horse-power per hour is $\frac{1150}{86.6}$ equals 13.2, which is less than one half that used when following full stroke.

Owing to the fact that there are many losses due to back pressure, clearance, friction of the steam in passage and condensation, this amount of economy is seldom met with in actual practice.

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CHAPTER XVII

POWER-GENERATING MACHINES

Steam Engines and Turbines

1711. The Steam Engine. Steam engines may be divided according to the number and arrangement of their cylinders into simple, compound, triple-expansion, quadruple-expansion, duplex, etc.; according to the type of valve and valve gearing used, into plain slide valve, piston valve, automatic cut-off, Corliss, etc.; and according to their use, into stationary, locomotive and marine. Any of the above may be either single or double acting as the steam is admitted to one or both sides of the piston; horizontal or vertical as the center line of the engine cylinder is horizontal or vertical; and condensing or non-condensing when exhausting into a partial vacuum or into the atmosphere.

The details of the simple slide-valve engine are so well known that an enumeration of their names and functions would almost seem superfluous. However, the following figure (Fig. 1711) with lettered details may prove of service to the novice.

The cut represents a typical vertical piston valve engine as built by the Buffalo Forge Co., the principal parts of which are the cylinder, *Cyl*, in which reciprocates the piston, *P*. The reciprocating motion of the piston is transformed into the rotary motion of the shaft through the piston rod, *PR*, the cross-head, *CH*, the connecting rod, *CR*, and the cranks, *C*. To the shaft is attached the eccentric, *E*, by means of which motion is given to the valve *V*, and the fly-wheels *W* which serve the double purpose of steadying the rate of rotation and of transmitting the power. The fly-wheel nearest the eccentric contains the governor, *G*, which by shifting regulates the amount of steam at any stroke.

The movement of the valve across the ports, *p*, is effected by the eccentric, through the eccentric rod, *ER*, the slide, *S*, and the valve rod, *VR*, to the valve. The relative position of the crank and eccentric is "quartering"; that is to say, that when the piston

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reaches the end of its stroke the valve has reached the middle of its stroke. Steam enters the steam chest, *SC*, through the steam-pipe and fills the space *X* between the two portions of the valve. The passage of the steam is as follows: With the piston at the

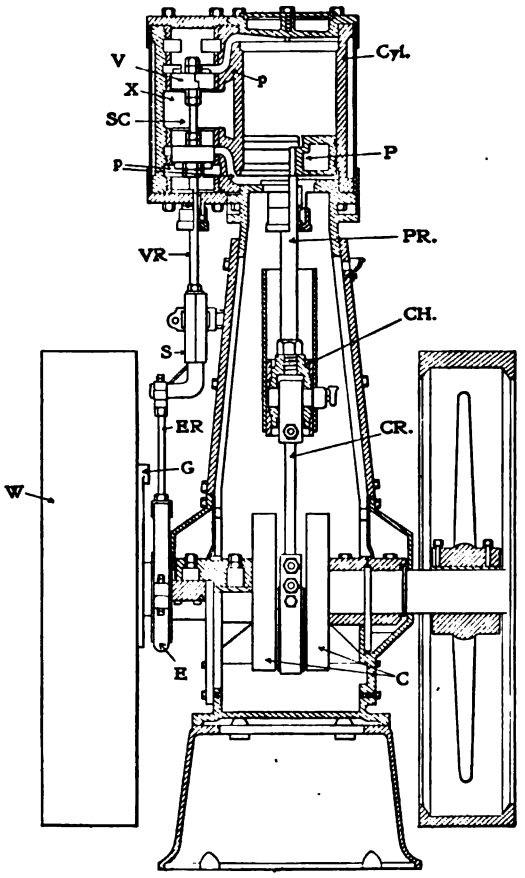

FIG. 1711. — Section of a Vertical Piston Valve Engine.

bottom of the cylinder as indicated, the valve moves downward, uncovering the lower port and admitting steam underneath the piston, forcing it up and causing the steam above it to be exhausted through the upper port, which latter is open to the atmosphere. By this time the valve has moved upward so as to admit steam through the upper port, thus forcing the piston

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down to its original position, compelling the steam which forced the piston up to be exhausted through the lower port. This action is continuous and automatic.

1712. Turbines. A steam turbine generally consists of a disc or cylinder with properly formed buckets or blades on the circumference, against which the steam impinges at a determined angle. In its simplest form it is a turbine wheel operated by steam instead of by water as is the ordinary turbine.

The most important reason for the high efficiency of the turbine is that it is adapted to use effectively the highest possible degrees of expansion; while in the reciprocating engine it is practically impossible to provide for high degrees of expansion. As the exhaust pressure approaches a perfect vacuum, the volume naturally increases at a rapid rate — the volume of steam with a 29-inch vacuum being double that with a 28-inch vacuum. In the turbine the highest degree of expansion is easily provided for because of its immense advantage in the use of a very high vacuum and all degrees of superheat. Consequently a much larger portion of the heat (work) in steam can be utilized by turbines than by steam engines.

The respective weights of complete generating units exclusive of foundations — reciprocating engine and turbine — are in the ratio of 8 to 1, and the saving in foundations alone is a very important item.

The important steam turbines on the market are the Dow and the Pyle, the DeLaval, the Curtis and the Westinghouse-Parsons. The Dow and the Pyle have their chief use in locomotive head-light work. The DeLaval is very efficient and is built in sizes up to 300 horse-power, while the Curtis has its chief use in direct-connected generator work, generally in large plants, and is built in units up to 5000 kilowatts. The Westinghouse-Parsons is built in larger sizes than any other, the largest on the market being 10,000 kilowatts or 15,000 horse-power. It is used extensively for both marine and electrical generating work.

1713. The Dow and Pyle Turbines. The Dow turbine is a series of radial outward-flow turbines placed like a series of concentric rings in a single plane with a stationary guide ring between each pair of movable rings.

The Pyle turbine is similar to the Dow, with the exception that it consists of inward-flow turbines. These two types of

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turbines are extensively used for small self-contained generating plants on locomotives for electric head-light work.

1714. The DeLaval Turbine. In the DeLaval turbine the steam enters a ring-shaped chamber surrounding the casing of

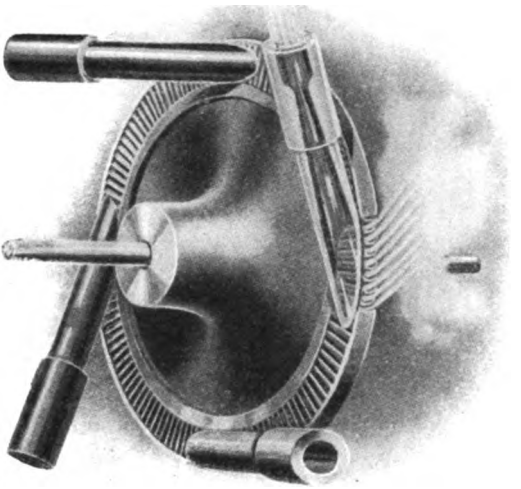

FIG. 1714*a*. — Action of Steam in DeLaval Turbine.

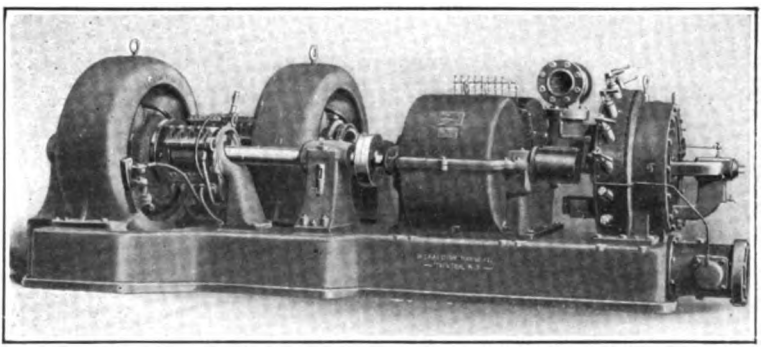

FIG. 1714*b*. — DeLaval 200 K. W. Twin Generator Set.

the turbine and from this it enters several nozzles that convey the steam to the turbine buckets, which are fastened to the circumference of a single disc. A steam jet is directed by these

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nozzles against the plane of the turbine at quite a small angle, and tangentially against the medium circumference or center line of the buckets. The interior of these nozzles is tapered with the large end toward the buckets, and the steam in passing through the nozzle, expanding freely to the pressure of the surroundings, acquires great velocity. The energy due to this velocity is imparted by impact to the buckets, thereby rotating the wheel.

Kent makes the following remarks in reference to the DeLaval steam turbine: "As the steam passes through the channel or nozzle, its specific volume is increased in a greater proportion than the cross-section of the channel, and for this reason its

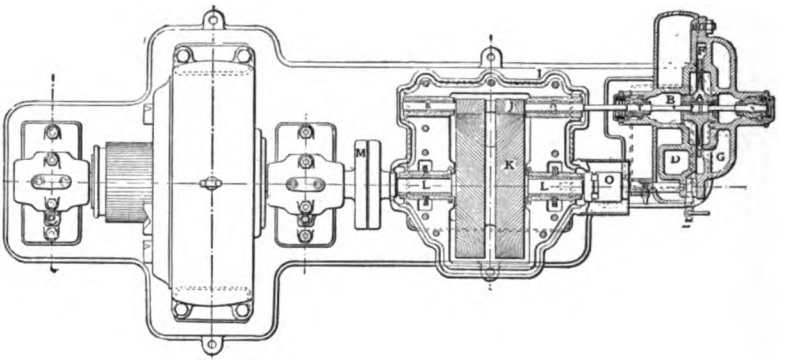

FIG. 1714c. — Sectional Plan of DeLaval Turbine Dynamo.

velocity is increased and also its momentum, till the end of the expansion at the last sectional area of the nozzle. The greater the expansion in the nozzle, the greater its velocity at this point." Expansion is carried further in this steam turbine than in ordinary steam engines. He further states that to obtain the best possible effect, the admission to the blades must be free from blows and the velocity of discharge as low as possible. These conditions would require in the steam turbine an enormous velocity of the periphery, as high as 1300 to 1600 feet per second. On account of centrifugal force, the velocity of the periphery of a 5 horse-power turbine is .574 foot per second, the number of revolutions being 30,000 per minute.

The inability to secure a coincidence of the center of gravity and the geometrical axis of revolution, on account of the unevenness in the texture of the material, necessitates such provisions

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and adjustments as will allow the rotating mass to adjust its center of rotation to its center of gravity. This is generally accomplished by the use of a flexible shaft, movable bearings, or the use of a bearing which is kept filled with oil at a very high pressure.

As will be seen from Fig. 1714*c* the speed reduction necessary for ordinary purposes is effected by means of the gearing *J K*. This type of turbine is built in units up to 300 horse-power.

1715. The Curtis Turbine. In the Curtis turbine no attempt is made to keep the speed of the vanes up to one half that of the jet — this is a condition of economy in the DeLaval — for it is

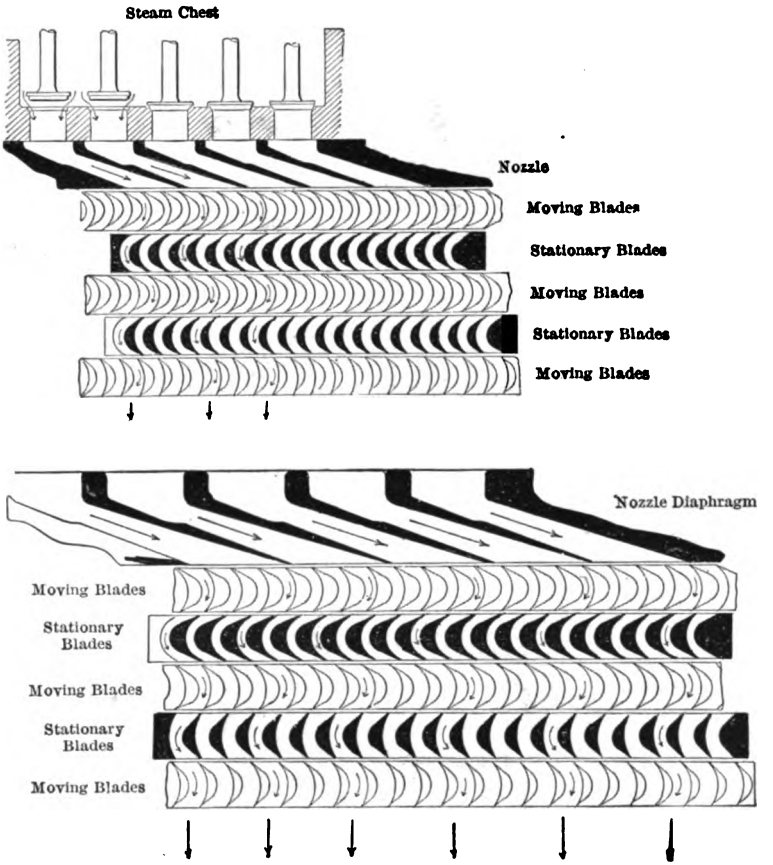

FIG. 1715*a*. — Diagram of Curtis Nozzles and Buckets.

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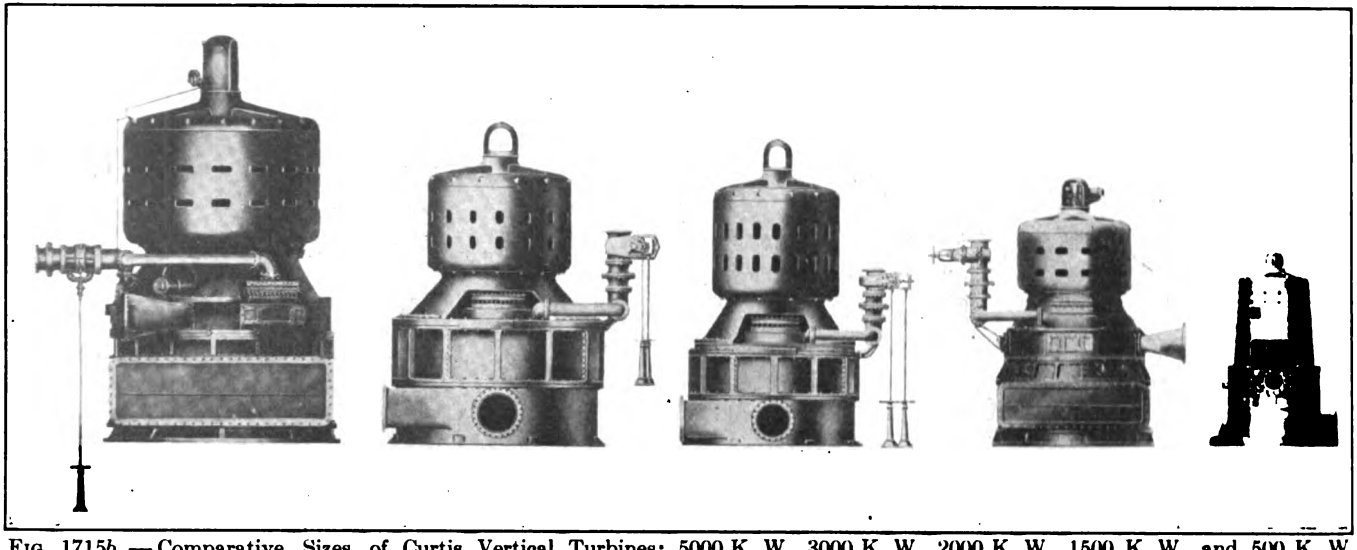

FIG. 1715*b*. — Comparative Sizes of Curtis Vertical Turbines; 5000 K. W., 3000 K. W., 2000 K. W., 1500 K. W., and 500 K. W.

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not sought to take all the velocity out of the jet in the first bucket. What remains after the first bucket is passed is not wasted but absorbed by the series which follows. The following description is taken in part from *Power* and from the General Electric Co.'s pamphlet by Mr. Emmett:

A comparatively high initial velocity is given to the jet by expansion in a nozzle or set of nozzles in parallel as in the DeLaval, and this velocity is absorbed by successive action upon a series of alternately movable and stationary vanes arranged as in the Parsons, with this difference, that while in the Parsons turbine there is a sufficient difference in pressure between the two sides of each vane to induce the flow, and a continuous expansion, the successive vanes in any one stage of the Curtis are used simply to absorb the velocity or momentum already generated by expansion in the nozzle. See Fig. 1715*a*. When the initial velocity has been absorbed, motion is again generated by expansion in another set of nozzles of an area sufficiently greater than the first to allow for the increase of volume by the previous expansion, and the operation is repeated upon another and larger set of vanes.

This process of expansion in the nozzle and subsequent abstraction of velocity by successive impacts with the vanes is designated as a stage, of which there may be several. The general practice is to so divide up the steam expansion that all stages handle about equal parts of the total energy of the steam.

Curtis turbines in units of 5000 kilowatts are in successful operation.

1716. The Westinghouse-Parsons Turbine. The Westinghouse-Parsons turbine is a series of parallel flow turbines mounted side by side on a shaft or cylinder and having in the casing a stationary guide ring, carrying blades or buckets between each turbine.

The following is a description of the Westinghouse-Parsons turbine, of which Fig. 1716*a* is a longitudinal section:

Steam is shown as entering at *S* where a strainer is provided, thence through the poppet valve *V*, controlled by the governor, to the admission port *A* and passes out to the left through the turbine blades, eventually arriving at the exhaust chamber *B*. The blades are similar to those shown in a previous figure (Fig. 1715*a*), the steam passing first a set of stationary blades and im-

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pinging on the moving blades, driving them around and so on. The areas of the passages increase progressively in volume, corresponding with the expansion of the steam. On the right of the steam inlet are shown revolving balance pistons P, P, P, one corresponding to each of the cylinders in the turbine, which according to size may be 1, 2, 3 or 4 in number. The steam at A presses against the turbine and goes through doing work. It also presses in the reverse direction, but cannot pass the piston P, but at the same time the pressure, so far as the steam at A is concerned, is equal and opposite, so that the shaft is not subjected to any end

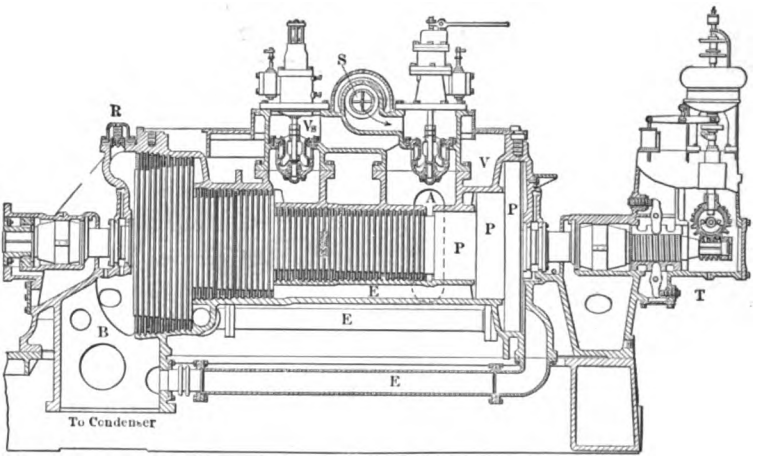

FIG. 1716a. — Sectional Elevation of Westinghouse-Parsons Turbine.

thrust. By means of the equalizing ports or pipes E the pistons are subjected to the same pressure as that acting on the various drums.

The areas of these balance pistons are so arranged that no matter what the load may be, or what the steam pressure or exhaust pressure may be, the correct balance is preserved and the shaft has no end thrust whatever.

At T is shown a thrust bearing which, however, has no thrust to take care of, but serves to maintain the correct adjustment of the balance pistons.

This turbine is built in units up to 10,000 kilowatts or 15,000 horse-power.

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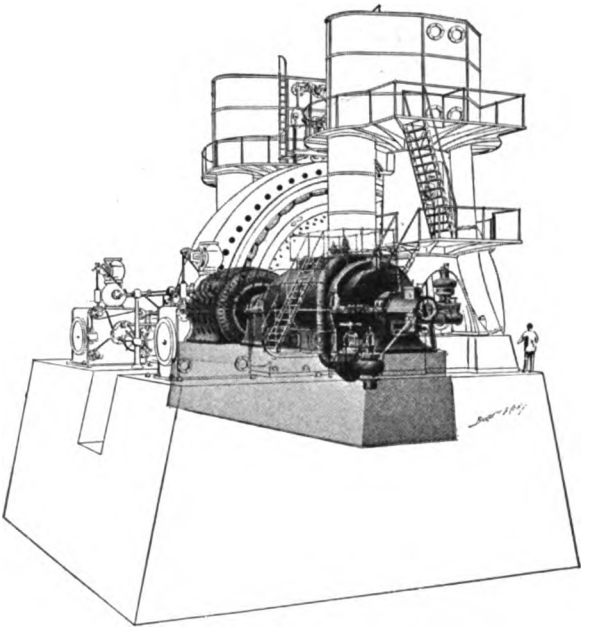

FIG. 1716b. — 5000 K. W. Generating Units. Comparison of Space Occupied and Size of Foundations. Modern Engine Type Unit, and a Westinghouse-Parsons Turbine Type Unit of similar Rating and Overload Capacity.

1717. Table of Comparative Steam and Coal Consumption.

Comparative Steam and Coal consumption per 1 horse-power-hour of the various types of engines:

Kind of Engine	Steam	Coal
Small Engines, Simple, Non-Condensing	40—50	6—12
Medium Engines, Simple, Non-Condensing	30—32	4—6
Medium Engines, Simple, Condensing	25—30	4
Compound Engines, Condensing	16—18	2
Triple-Expansion Engines, Condensing	14—15	1.75
Quadruple-Expansion Engines, Condensing	12—13	1.5
Brotherhood Rotary Engine	40—50	6—12
Cycloidal Engine		
Pyle Steam Turbine	35—45	5—7
Dow Steam Turbine	35—45	5—7
Westinghouse-Parsons Steam Turbine	16—20	2.3
DeLaval Steam Turbine	14—20	2.2
Curtis Steam Turbine	15—20	2.3

FIG. 1717.

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Gas, Oil and Hot Air Engines

1721. Theory and Thermodynamics. In the chapter on "Mechanics" we discovered that one thermal unit of heat was produced by the expenditure of 778 foot-pounds of work. In a thermodynamical discussion of heat and work, we discover that the greatest amount of work which can possibly be obtained from a heat-engine in its conversion of a given quantity of heat is:

$$\text{Work} = \frac{T - t}{T + 460} \times \text{Total Heat}$$

where T and t are the temperatures on the Fahrenheit scale between which the perfect heat engine is working — 460 being absolute zero on the Fahrenheit scale.

In the application of these two laws to the steam engine, the first step in the process was to increase the elasticity or pressure of the gas (steam) by heating it in a closed vessel. The steam was then passed into a cylinder and expanded, during which process a portion of the heat was converted into useful work, the residue escaping from the cylinder at a lower temperature. This we discovered to be a wasteful process, the best steam engine having a thermal efficiency of from 21% to 23%. Gas and oil engines seek to eliminate the waste due to the complicated apparatus for heating and increasing the pressure of the gas (steam) by internal combustion, that is by generating heat and pressure directly in the cylinder of the engine.

1722. Beau De Rochas' Conclusions — Otto and Clerk Cycles. In 1862 Beau de Rochas announced the four following conditions to be necessary to secure the best results from an expanding gas: (1) The cylinder should have the greatest capacity with the smallest circumferential surface; that is, a cylinder whose length is equivalent to its diameter. (2) The speed should be as high as possible. (3) The cut-off should be as early as possible. (4) The initial pressure should be as high as possible. This postulates that ignition of the gas should take place at the dead point; such, however, is not the practice with modern engines, for it has been discovered that in this class of engines and in guns — in which the action of the gas is analogous — better results are secured where the rise of pressure is more gradual and its intensity partially sustained. Practice shows that two important

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advantages are secured by so doing; first, starting is made easier, and second, though the area of the diagram is diminished, the brake power is increased.

There are two characteristic cycles under which the greater portion of gas and oil engines operate:

The Otto or four-cycle in which the following sequence of operations takes place every two revolutions of the fly-wheel or every four strokes of the piston: (1) The inspiration of the explosive mixture during the entire first forward stroke. (2) Its compression during the next or return stroke. (3) Ignition at or near the dead point and expansion during the next stroke. (4) The expulsion of the burnt gas during the fourth stroke.

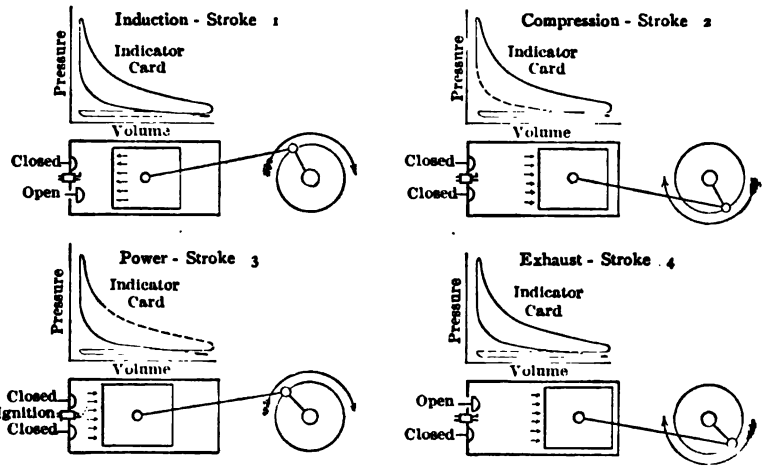

FIG. 1722*a*. — Operations in Four-cycle Engines.

In the Clerk or two-cycle the following sequence obtains: (1) The admission of the compressed explosive mixture and its further compression during the return stroke, and (2) the ignition, expansion and expulsion of the gas on the forward stroke.

In his discussion of these two cycles, Dugald Clerk, while realizing the advantages of the Otto cycle, truthfully charges it with the production of engines which are subject to intermittent action and excessive forces incompatible with uniformity, durability and ease of operation. He further states that the Otto cycle requires cylinders enormously large by reason of the small mean effective pressure developed by the gas which operates by

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explosion rather than by combustion; and again, in cases where the regulation is effected by the admission of a variable quantity of the explosive mixture the compression is not generally a constant.

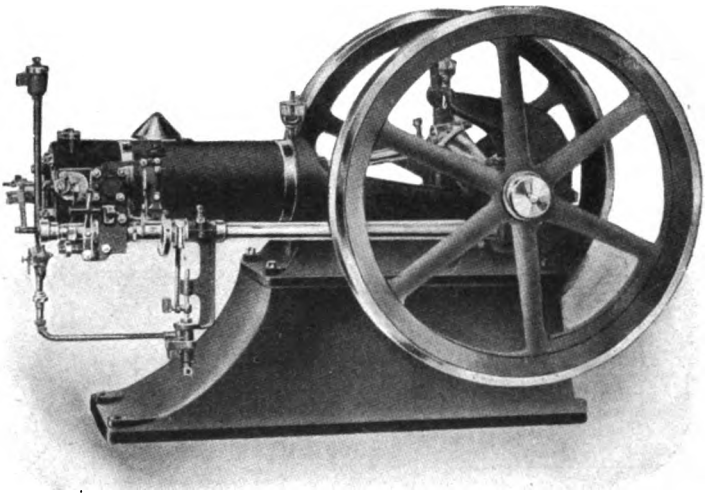

FIG. 1722*b*. — Otto Gas Engine.

One of the great advantages of the Otto cycle, however, is that it lends itself readily to a design of engine which is at once simple in mechanical construction, efficient in the use of fuel and easily operated.

1723. Discussion of Details and Methods of Regulation. At the present time, the majority of the small stationary gas and oil engines operate on the Otto cycle with what is called the "hit or miss" system of regulation.

The "hit or miss" system of regulation is based on the opening of the gas admission valve under the action of the governor, the air admission being independent and occurring at each cycle with the result that, as the load fluctuates, the number of admissions and explosions varies accordingly. The proportions of the mixture are regulated once for all while the compression remains a constant.

For the reason that it is required simply to displace a little piece of metal between the stem of the admission valve and the

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cam, the "hit or miss" system of regulation is one of great sensitiveness in the governor mechanism, it being subject to no reaction by the details which it operates.

Small two-cycle engines are used to a considerable extent for launch and automobile work. In Europe the tendency of practice for the larger engines, those over 100 horse-power, is toward the Koerting type. The Koerting engine is double-acting, as are most steam engines; it operates on the Clerk cycle and has the combustible charge of gas and air delivered to, and the burnt gases extracted from, the cylinder by means of two auxiliary

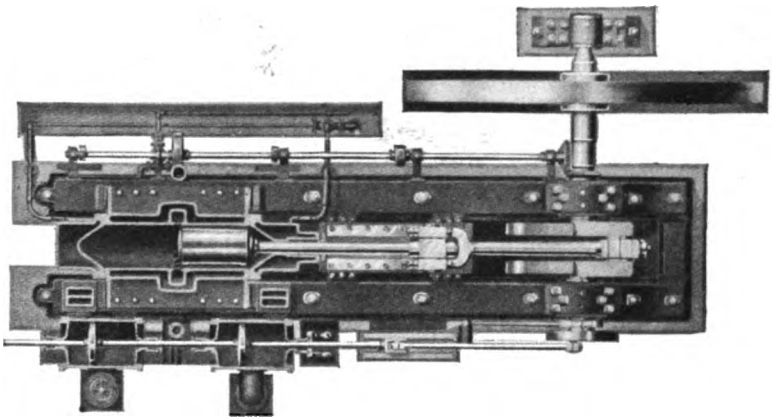

FIG. 1723*a*. — Sectional Plan of Koerting Two-cycle Gas Engine, Showing Piston, Main, and Charging Cylinders.

cylinders — one an air, the other a gas — which serve as pumps. These cylinders are so proportioned that the proper combustible mixture is delivered to the working cylinder by the action of two piston valves. The engine is regulated by a throttling device under the control of a governor. This type of engine operates either on blast or producer gas and has a thermal efficiency, according to Professor Meyer, of 38%. It is made in horse-powers ranging from those in hundreds to those measured in thousands.

Uniformity of rotation is secured in the single-cylinder engines only by the use of excessively large and heavy fly-wheels which reduce the mechanical efficiency to 80% or 82% instead of 85% to 90%. In nearly all of the large gas engines, and especially those which operate on the Otto cycle, the manufacturers have

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endeavored to secure uniformity of turning effort by increasing the number of the cylinders. American practice tends toward a multiple cylinder, vertical four-cycle engine, while European practice is toward a two-cylinder, horizontal, two-cycle engine, where economy of consumption is sacrificed to obtain a minimum number of moving parts and a uniform turning effort.

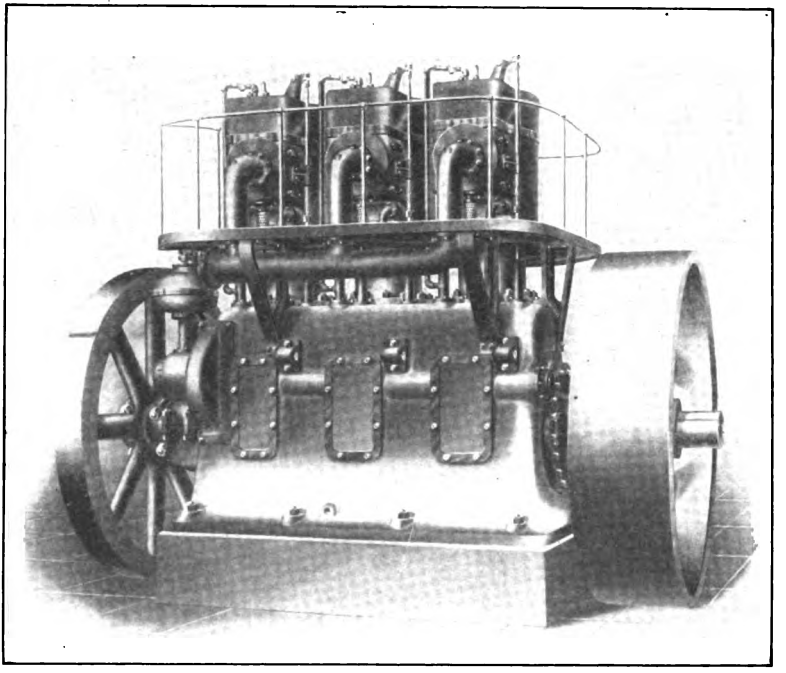

FIG. 1723*b*. — Westinghouse Vertical Gas Engine.

One of the best known Americanized engines is the Diesel engine, manufactured at Providence, R. I., the latest type of which has three vertical cylinders mounted symmetrically and all driving the same shaft, each cylinder operating independently on the Otto cycle.

1724. The Diesel Engine. From a description published in *Power*, April, 1903, we learn that: "The Diesel engine has three distinctive characteristics as compared with existing explosive gas and oil engines. They are (1) The content of the cylinder during the compression stroke is air only and the temperature

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due to compression is far above that which is necessary to ignite the combustible charge. (2) The clearance is only about 7% of the cylinder volume and in this space is confined, under great pressure, more than enough air to supply oxygen for the combustion of any amount of fuel the engine is designed to use.

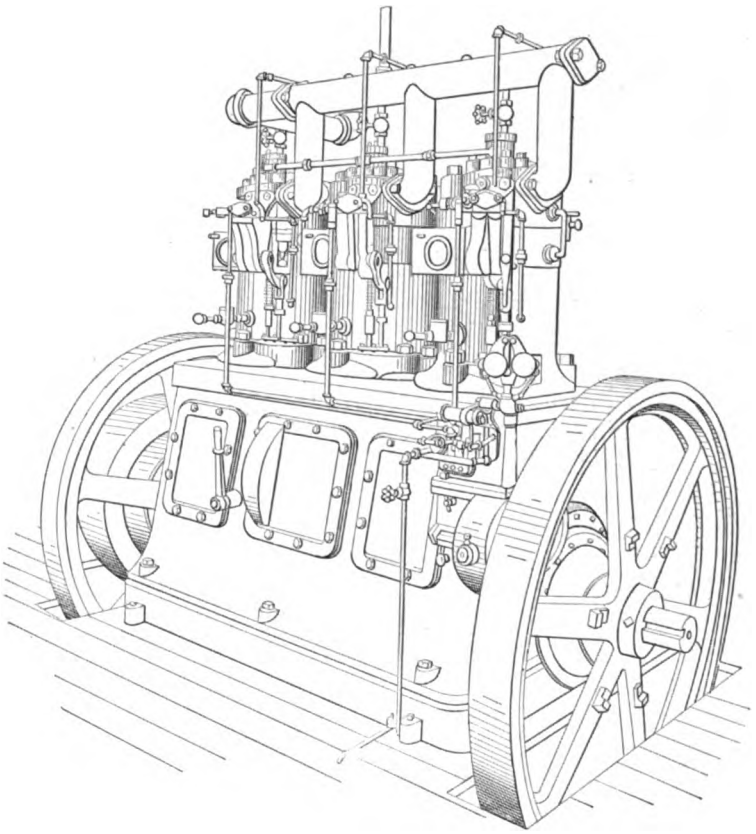

FIG. 1724. — 750 B.H.P. Diesel Engine.

(3) The combustion of the fuel is not an explosion, but it burns as fast as injected into the cylinder without increasing the pressure produced by compression. . . . The opening of the fuel valve allows the compressed air — compressed by an auxiliary cylinder — to drive out through perforated washers the oil in the form of a fine spray. It is driven into the cylinder and ignited by the

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extremely high temperature of the air compressed by the up stroke of the piston. Any grade of crude or fuel oil may be used. The air which supports combustion is drawn into the cylinder through an automatic mushroom valve and compressed by the up stroke of the piston to between 450 and 525 pounds per square inch. The resulting temperature approaches 1000 F. and this is much more than sufficient to ignite the oil as soon as it is injected. At the commencement of the down stroke the fuel valve opens, remaining open about a tenth of the stroke, and fuel is admitted and burned — in no sense exploded — during the whole or part of this period, according to the action of the governor. After the fuel supply is stopped, the resulting gases of combustion work expansively during the rest of the stroke."

Tests of this engine show a thermal efficiency of 41.83% and tests on a single-cylinder engine of this type produced a brake horse-power per hour on ½ pound of ordinary crude oil. The reliability of this engine is evinced by a continuous run of over two weeks in which the operation was absolutely without stop and the variation of electrical pressure generated was very small.

1725. Fuels. As may be gathered from the foregoing text, and from Figs. 1725*a* and *b* on pages 394 and 395, the fuels employed in these engines vary widely. Of the gases commonly used, we may mention ordinary illuminating gas, producer gas and the waste gases from blast furnaces. Many gas and gasoline engines operate on carbureted air, the air being passed over gasoline or some other volatile petroleum spirit of low specific gravity, is saturated with vapor and becomes equal in heating or lighting power to ordinary coal gas. Great caution should be used in the handling of gasoline, the danger arising because the vapors given off at ordinary temperatures are highly explosive. One of the defects of a common form of carbureter is that the more volatile oils are first taken off, leaving what is sometimes a useless oily residue. To obviate this difficulty some manufacturers spray the gasoline into a current of air by which it is vaporized; the mixture is then compressed and ignited by an electric spark. When gasoline is so used, it should be led from an underground tank through soldered pipes to the combustion chamber, and at no time should it come in contact with the air outside of the engine. There should never be any flame

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or burning gases in the vicinity of the cylinder, except of course, in the case of hot tube ignition, where it is a feature of the engine.

Motors of the Priestman and Diesel type operate on the less volatile petroleum products such as kerosene, partially refined or even crude oil. If for no other cause than the low cost of fuel, the gasoline engine is rapidly superseding the small steam engine, for as early as 1893 the cost of fuel at retail for small gasoline engines was on a par with the steam engine using 6 pounds of coal per horse-power hour, with coal at three dollars and one half per ton. The saving here would be the cost of attendance for boilers and the handling of the solid fuel and ashes. The cost of operation for a gasoline engine requiring one tenth gallon per horse-power per hour, with gasoline at eight cents per gallon, would be .8 cents per horse-power per hour.

1726. Operation. Gas engines, unlike steam engines, do not start without the aid of some auxiliary starting device. Starting devices have taken various forms according to the ideas of the manufacturers; some of the methods employed being a crank turned by hand for the smaller sizes; a simple means of placing a starting charge in the cylinder; or the starting may be effected by the use of compressed air.

The life of the ordinary gas engine is far shorter, for the reasons stated by Clerk, than the life of the ordinary steam engine of the same horse-power. However, this mechanical difficulty is being rapidly solved both in America and in Europe. At present this short life offsets to some degree the economy of the gas-engine plant.

1727. Naphtha Engines. Naphtha engines use naphtha in the boiler instead of water, the vapor being used expansively in the engine cylinder as steam is used. Upon being exhausted it is condensed and returned to the boiler; a portion of the naphtha, however, being used as fuel under the boiler. These engines are used almost exclusively for small yachts and launches. A 4 horse-power engine weighs 300 pounds, consumes from 4 to 6 quarts of naphtha per hour and takes but about two minutes to get under headway.

1728. Hot-air or Caloric Engines. Hot-air engines are used to some extent for pumping small quantities of water, but their bulk is enormous compared with their effective power. The heat

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Commercial Power Gases — General Properties

Courtesy Westinghouse Machine Co.

	Gas	Origin	General Characteristics for Power Work	Appx. Order of Value for Power Gas
1	Natural Gas	Geological. — Results from decomposed vegetation.	Ideal power gas. Rich, pure, rather slow burning. Requires no cleaning.	1
2	Oil Gas	Vaporizing crude oil. Used to enrich water gas.	Very rich in heavy hydrocarbons. Liable to carbon deposits. Seldom used for power except in small oil (petrol) engines.	9
3	Coal Gas	Destructive distillation of coal in closed retorts.	Excellent gas, resembling natural gas. Not hard to clean. Manufacturing costs usually too high for general power purposes.	8
4	Coke-Oven Gas (By-product)	Liberation of volatiles of coal in closed chambers without combustion.	Gas should be drawn off during early part of coking run. Good gas, rather high in H & S, requiring much purification.	5
5	Water Gas	Decomposition of steam on incandescent coke. Hydrogen freed, carbon burned to CO.	Pure gas, too snappy (high in H) for gas engines. More suitable if enriched with oil gas. Rather expensive gas for general power purposes.	10
6	Oil-Water Gas	Decomposition of steam and oil in retort heated by crude oil.	Rich gas, high in H, and rather snappy. Free from impurities, except S. Manufacturing cost low.	6
7	Producer Gas	Obtained from coal, coke, peat, lignite or wood. Largely incomplete oxidation of carbon to CO by a steam air blast. H_2O decomposes into free H. Some CO_2 formed.	Cheapest and best of artificial fuel gases, lean and comparatively slow burning. Made from any grade fuel.	2
8	" Bituminous	Bituminous coal. Breaking up of volatile hydrocarbons and conversion of fixed carbon into CO.	Richest of producer gases. Tar distillate difficult to remove. Most grades of coal suitable, including slack, lignite, and wood.	2
9	" Anthracite	Anthracite coal. Practically no volatiles. Conversion of fixed carbon.	Gas free from tar,— requiring little cleaning. Excellent power gas. Buckwheat size coal may be used.	3
10	" Coke	Coke or charcoal. — No volatiles. — Conversion of fixed carbon.	Gas practically clean, except dust. Most suitable for small producers. Fuel rather expensive.	7
11	Blast Gas	By-product of blast furnaces. — Conversion of fixed C in coke into CO by air blast. Some CO_2 formed.	Gas very lean, dusty, and sluggish. Difficult to clean except mechanically. Excellent gas for engines taking high compressions.	4

Fig. 1725a.

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CONSTITUENTS OF POWER GASES — GENERAL PROPERTIES

Courtesy Westinghouse Machine Co.

GAS		HEATING VALUE		Characteristics — Where Found
Name	Chemical Symbol	B. T. U. Cu. Ft. Net	Relative	
Hydrogen....	H	278	1	Element formed from decomposition of steam (H_2O) or hydrocarbon compounds. Burns very rapidly with high flame temperature.
Oxygen.....	O	0		Element, not considered a combustible as it displaces an equal amount of (O) in air for combustion.
Nitrogen.....	N	0		Element. Inert gas entering with air (N-79%, O-21%). Retards speed of combustion.
Carbon Monoxide or Carbonic Oxide.	CO	326	1.17	Valuable constituent. Product of incomplete combustion (oxidation) of C in presence of excess carbon.
Carbon Dioxide.....	CO_2	0		Inert gas. Product of complete combustion of C. Occurs in all producer and blast gases. Retards speed of combustion.
Methane or Marsh Gas..	CH_4	913	3.29	Most valuable constituent evolved by natural or artificial decomposition of vegetable matter, coal or crude oils.
Acetylene....	C_2H_2	1427	51.4	Higher hydrocarbons, usually as "illuminants" — occur in small quantities in the richer gases liberated during destructive distillation of coal or oil — Acetylene used alone for lighting.
Ethylene or Olefiant Gas	C_2H_4	1490	53.6	
Ethane.....	C_2H_6	1615	58.1	
Benzine or Benzol	C_6H_6	3655	131.5	
Carbon	C			C oxidizes to CO (incomplete) and CO_2 (complete). CO oxidizes to CO_2.
Sulphur	S			S oxidizes to SO_2 forming H_2SO_4 (sulphuric acid) with water.

FIG. 1725*b*.

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of a slowly burning fuel is applied to the piston and rejected at the end of the stroke. The following data are compiled from a test, made by Professor Robinson, of a twelve nominal horse-power hot-air enigne:

"This engine gave 20.19 I.H.P. in the working cylinder and 11.38 I.H.P. in the pump, leaving 8.81 net I.H.P.; while the effective brake H.P. was 5.9, giving a mechanical efficiency of 67%. The consumption of coke was 3.7 pounds per brake H.P. per hour; while the mean effective pressure on the working pistons was 15.37 pounds per square inch; in the pumps it was 15.9 pounds. The area of the working cylinders was twice that of the pumps. The temperature of the hot air supplied was about 1160 degrees F., it being rejected at the end of the stroke at a temperature of 890 degrees F.

Hydraulic Motors

1731. Water Wheels. A shaft may be rotated by water in one of the three following ways: by weight, by impulse and by reaction. Very few wheels act wholly by either of these modes, the wheel taking this or that form as one or the other modes of action preponderates.

The characteristics of water wheels are that they operate by the weight of the water and move with a low velocity, the velocity having no definite relation to the height or head of the water under which the wheel operates. Paddles, blades or buckets are fastened to a shaft or to a "spider" in such a manner that the weight of the water on them rotates the wheel. The wheels are designated as *undershot*, those which receive the water below the center; *overshot*, those which receive the water at or near the top and running contrary to the undershot; and *breast*, those which receive the water above the center and below the top and run the same as the undershot. The efficiency of water wheels varies as follows, Merriam giving this efficiency: overshot wheels, 70% to 90%; breast wheels, 50% to 80%, with the lower values on the smaller wheels; undershot — with the exception of Poncilot, which on account of its peculiar construction has an efficiency of 60% — 20% to 40%.

1732. Turbines, Theory and Discussion. The word turbine when used in hydraulics generally refers to an impulse or reaction wheel, the principle characteristic of which is that it runs with a

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velocity which has a definite relation to the head under which it operates. In the following discussion taken in part from G. C. Mark's excellent work on "Hydraulic Power Engineering," the friction losses are neglected and the matter is presented theoretically.

If a stream of water having a certain velocity, *Vw*, encounters a curved vane, the path of the stream will be altered, following the curve of the vane and leaving it in the direction which the vane would take were it continued. The velocity, *Vw*, of the leaving stream will be the same as on entering the vane, the only change being one of direction. Should a velocity, *Bv*, be given to the vane, an inspection of the diagram will show that the water may never reach the vane, for when the stream has reached *Vx* the vane will have traveled to *B'v*.

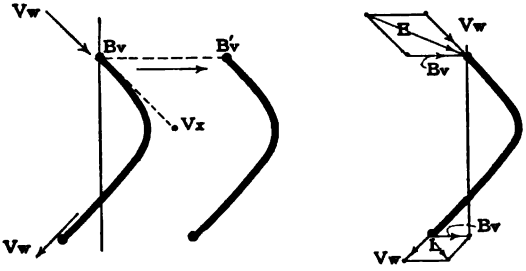

FIG. 1732.

To obviate this, either the orifice of the stream must be given a motion similar in direction and magnitude to *Bv*, or the direction and velocity of the stream must be altered to *E*, the resultant of *Vw* and *Bv*. The motion of the stream relative to the moving vane again coincides with *Vw*. The motion of the stream on leaving the vane will again coincide with *vw*, relatively to the vane, but as the vane and stream each have the velocity *Bv*, the absolute or real velocity of the stream on leaving the vane will be the resultant of *vw* and *Bv* or *L*. On entering the vane the stream has an absolute velocity of *E* and a corresponding store of energy of $\frac{WE^2}{2g}$ while on leaving the vane the amount was $\frac{WL^2}{2g}$

When *L* is less than *E* the difference has been applied to the vane, and may be applied in the performance of useful work.

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The velocity E of the head being fixed, the velocity L of the discharge should be made as low as possible, but never zero, as then the water would not flow from the vane. The only governing condition for the curve of the vane is that the water flow gradually from the angle of entry to the angle of exit.

J. P. Frizell points out, in a discussion more particularly of cup-shaped vanes, that: (1) The purpose of the vanes or floats in an impulse wheel is to effect the greatest possible change in the motion of the water. Their length need be no greater than is necessary to accomplish that change, and (2) it is a condition of highest efficiency that the water should leave the vane in a direction opposite to its motion and with a velocity equal to that of the vane at the point of exit. Where the edge of the vane is radial to the wheel, different parts move with different velocities, and the fulfilment of this condition is impossible.

Frizell in his discussion of reaction wheels supposes the rim of a wheel to contain orifices which discharge the water in a direction absolutely tangential to the wheel. The pressure within the wheel is assumed to be greater than the pressure without, the difference in pressure being represented by the head H. If A represents the cross-section of the stream, W the weight of a cubic foot of water and V equals the velocity; the best velocity of the circumference then is that due to the head H at which the water issues. In this case the absolute tangential velocity of the water leaving the wheel is zero, while the energy imparted to the wheel is $2\ WAVH$, or twice the energy of the water under the given head. This does not imply that the wheel is capable of yielding an efficiency of 200%, for, in order that the water may issue from the orifice while the wheel is in motion, it must receive a tangential velocity equal to that of the wheel, and to impart this velocity requires an expenditure of energy, $WAVH$. This and the several losses incident to motion, together with that due to the deviation of the issuing stream from the direction of a tangent, must be deducted from the original energy, $2\ WAVH$.

1733. Turbines — Classes and Uses. The two classes of turbines, impulse and reaction, each contain several distinct types. The impulse turbines have no suction tube (see Mark's "Hydraulic Power Engineering," page 292 to 298) and the types are the Pelton or hurdy-gurdy wheel, the radial outward flow, the radial inward flow and the axial flow.

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In general it may be stated that reaction turbines are better adapted for large volumes of water with low heads, while the reverse is true of the impulse turbine.

1734. Impulse Wheels. In this class of wheels, those acting purely by impulse, the water issues from the orifices or nozzles with a velocity due to the head and impinges upon the vanes,

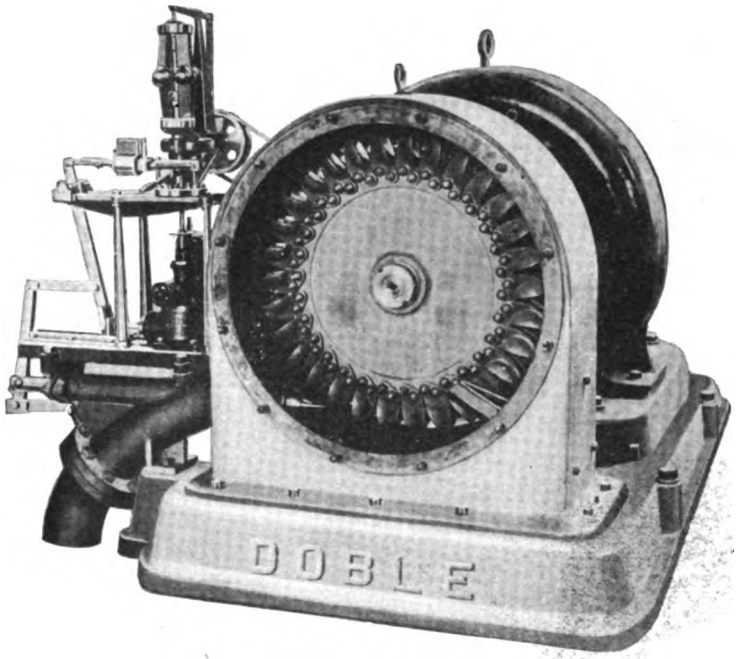

FIG. 1734a. — Interior of Doble Impulse Turbine.

which are cup-shaped and attached to the periphery of the wheel. The best known makes of impulse wheels are the Girard, the Doble and the Pelton; the latter is much used in this country and has a maximum efficiency of from 85% to 92%.

1735. Reaction Wheels. "Most wheels act partly by impulse and partly by reaction, and in the purely reaction wheels the work of the water is finished when it issues from the orifice of discharge." (Frizell.) Reaction wheels may be operated with or without a suction tube and are of the following types: radial outward flow; radial inward flow and axial flow. The best known

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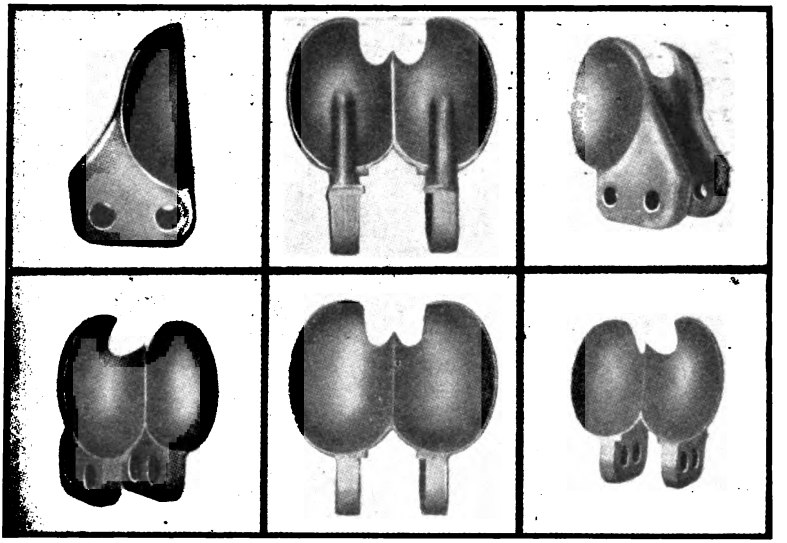

FIG. 1734*b*. — Doble Ellipsoidal Bucket after 14,000 Hours' Service under a Head of 1300 feet.

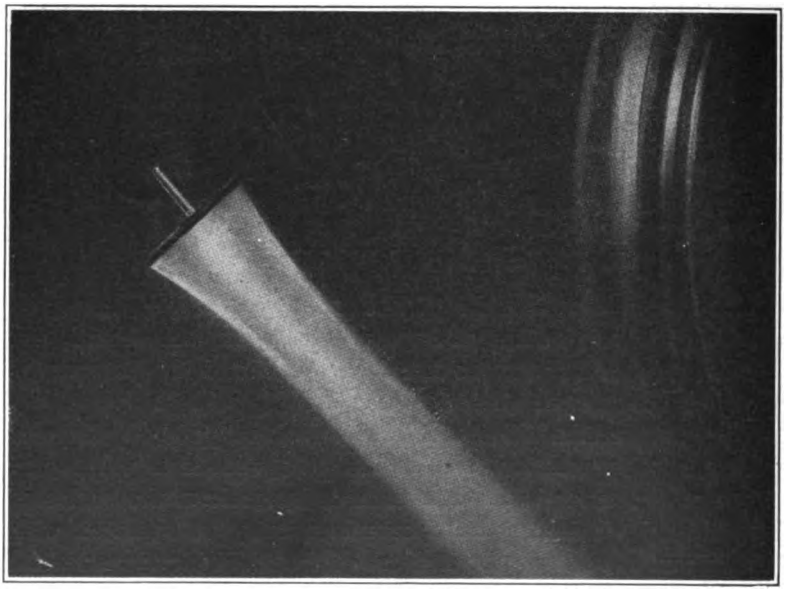

FIG. 1734*c*. — Action of Doble Needle Regulating Nozzle.

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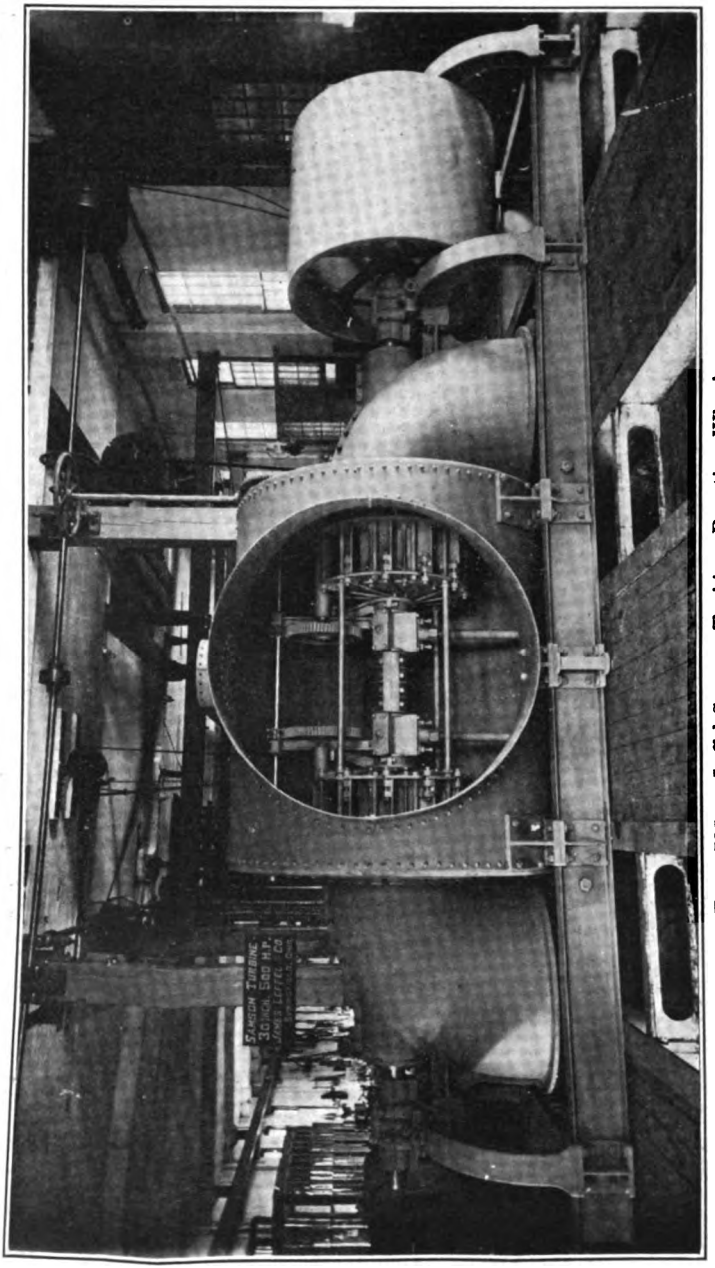

FIG. 1735. — Leffel Samson Turbine, Reaction Wheels.

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reaction wheels are the Boyden wheel, which as early as 1846 gave a net efficiency of 88%; the Swain; the American; the Risdon; the Leffel and the Duplex. The maximum efficiency of this class of turbine is from 75% to 90%.

The evolution of reaction wheels to this time has resulted in a form of wheel in which the water enters through openings having their longest dimensions parallel to the shaft, and leaves it through openings which have their longest dimensions radial to the shaft. The greatest difference between the various makes of wheels is mainly one of detail, either in the adaptation of the wheel to a horizontal shaft, in the shaft of the guides or vanes, in the gates and in the governing mechanism.

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CHAPTER XVIII

ELEMENTARY ELECTRICITY

NOMENCLATURE

1811. Standards, Laws and Facts. *Force.* That which tends to produce, alter or destroy motion is called force. There are two units of force, the pound and the dyne.

Dyne. That force which, acting on a mass of one gram for one second, will produce a velocity of one centimeter per second, is called a dyne.

Work. Work, as we have learned, is the production of motion against resistance, and its units are the foot-pound, the erg and the Joule.

Erg. That amount of work performed by a force of one dyne acting through a space of one centimeter is called an erg. The Joule is equivalent to 10,000,000 $(10)^7$ ergs; this larger unit is much used.

Energy — which is the capacity to do work — is of two kinds, kinetic and potential. Kinetic energy is that capacity to do work which a body possesses by virtue of its motion. Potential energy is that capacity to do work which a body possesses by virtue of its position; *i.e.*, that due to the separation or disarrangement of attracting particles or masses.

Kinetic energy equals $\frac{WV^2}{2g}$ where W is the weight of the body, V its velocity and g the attraction due to gravity.

Potential energy is measured by the amount of work required to put the body into its position or strained condition.

Power, whose units are the watt and the horse-power, is, as we have learned, the rate of doing work.

Watt, P, the performance of 10,000,000 $(10)^7$ ergs per second is termed a watt, or a watt is the power of a current of one ampere at a pressure of one volt; *i.e.*, watt equals ampere $\times$ volt. 746 watts are equivalent to one horse-power.

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Joule, W, is the unit of energy or work (volt-coulomb); it is practically equivalent to the energy expended in one second by an ampere flowing through a resistance of one ohm.

Ampere, I, is the unit of current strength or rate of flow and is equivalent to an unvarying current which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of .001118 grams per second.

Volt, E, is the unit of electro-motive force, the difference of potential or electrical pressure; and is that electro-motive force, which, steadily applied to a conductor whose resistance is one ohm, will produce a current of one ampere.

Ohm, R, is the unit of resistance and is the resistance offered to an unvarying electric current by a column of mercury at 32 degrees F., having a constant cross-sectional area, a weight of 14.4521 grams and a length of 106.3 centimeters.

Coulomb, Q, is the unit of quantity (ampere second) and is the amount of electricity transferred by a current of one ampere in one second.

The Ampere Hour, Q', is equivalent to 3600 coulombs.

Farad, K, the unit of capacity, is the capacity of a condenser charged to a potential of one volt by one coulomb of electricity.

Henry, L, the unit of induction, is the inductance of a circuit when the electro-motive force induced in the circuit is one volt, while the inducing current varies at the rate of one ampere per second.

Time, T, = one hour; t = one second.

The following formulas and their combinations express the relation between the above units; they are those in common use:

$$I=\frac{E}{R},\ Q=It,\ Q'=IT,\ K=\frac{Q}{E},\ W=QE,\ P=IE,\ Q=\frac{Et}{R},\ K=\frac{It}{E},$$

$$W=IEt=\frac{E^2t}{R}=I^2Rt=Pt.\quad E=IR,\ R=\frac{E}{I},\ P=\frac{E^2}{R}=I^2R=\frac{W}{t}=\frac{QE}{t}.$$

1812. Anologies between the Flow of Water and Electricity. In order to obtain a better understanding of the subject with the least expenditure of words, the following table of anologies, compiled from Kent and Suplee, is used:.

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ANALOGIES BETWEEN THE FLOW OF WATER AND ELECTRICITY

WATER	ELECTRICITY
Head, difference of level in feet. Difference of pressure, lbs. per square inch.	Volts; electro-motive force; difference of potential or of pressure; E or E. M. F.
Resistance of pipes, apertures, etc., increases with length of pipe, with contractions, roughness, etc.; decreases with increase of sectional area expressed by complex formulas.	Ohms, resistance, R increases directly as the length of the conductor or wire, and inversely as its sectional area, $R \propto l \div s$, or in the form of an equation $R = \frac{\text{a constant } K \times \text{length}}{\text{cross-section}}$. It varies with the nature of the conductor. Conductivity is the reciprocal of specific resistance.
Rate of flow, as cubic feet per second, gallons per minute, etc., or volume divided by the time. In the mining regions sometimes expressed in "Miner's Inches."	Amperes; current; current strength; intensity of current; rate of flow; 1 ampere = 1 coulomb per second. $\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$; $I = \frac{E}{R}$; $E = IR$
Quantity usually measured in cubic feet or gallons, but is also equivalent to rate of flow × time, as cubic feet per second for so many hours.	Coulomb, unit of quantity, Q = rate of flow × time, as ampere-seconds. 1 ampere-hour = 3600 coulombs.
Work or energy measured in foot-pounds; product of weight of falling water into height of fall: in pumping, product of quantity in cubic feet into the pressure in lbs., per square ft., against which the water is pumped.	Joule, volt-coulomb; W, the unit of work = product of quantity by the electro-motive force = volt-ampere-second. 1 Joule = .7373 ft. lbs. If I (amperes) = rate of flow and E (volts) = difference of pressure between two points in a circuit, energy expended = $IEt = I^2Rt$.
Power, rate of work, horse-power = ft. lbs. of work in one minute ÷ 33000. In water flowing in pipes, rate of flow in cu. ft. per second times resistance to the flow in lbs. per square foot ÷ 550; in falling water, lbs. falling in 1 second ÷ 150.	Watt, unit of power, P, = volts × amperes = current or rate of flow × difference of potential. 1 watt = .7373 ft. lbs. per second = $\frac{1}{746}$ of a horse-power.

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In the mechanical applications of electricity, it must always be remembered that the volt corresponds to pressure and the ampere to flow, and the product—the volt-ampere—is the watt, the unit of power, 746 of which are equal to a horse-power. The kilowatt equals 1000 watts, is equal to $\frac{1000}{746} = 1.34$ horse-power. The British Board of Trade Unit is equal to 1 kilowatt hour.

1813. Electric Circuits. A circuit is composed of a conductor or several conductors joined together, and is the path through which a current flows from a given starting point, around the conducting path and back to the point again. When some of the conducting elements are disconnected, the circuit is termed *open* or *broken* in contrast to being *closed* or *completed.* A circuit is said to be *grounded* when some of the conductors have come in contact with the ground, either themselves or through some ex-

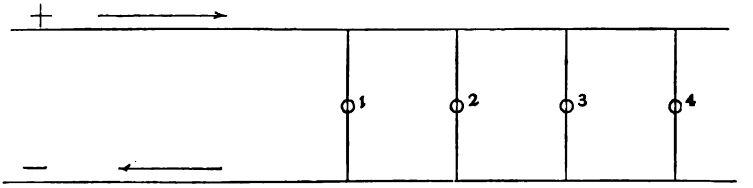

FIG. 1813. — A Divided Circuit.

ternal conductor. With dynamo electric machines the terms *external* and *internal* circuits are used; the former to indicate that part of the circuit which is outside the electric source; the latter, that part of the circuit which is included within the electric source.

A *divided* circuit is one divided into two or more branches, each branch taken separately being termed a shunt. A divided circuit may be shown as follows:

1, 2, 3 and 4 are the branches, this circuit having 4 branches, any one of which, as 1, 2, 3 or 4, is called a shunt to the others.

The term *series* is used to designate that sort of connection of conductors which allows the current to pass through each successively. Multiple arc or *parallel* is the term used to designate that sort of connection of conductors in which all the positive electrodes are connected to one main positive conductor and all the negative electrodes to one main negative conductor.

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The expression $I = \frac{E}{R}$ is Ohms law, which interpreted is — the strength of an electric current in any circuit is directly proportional to the electro-motive force developed in that circuit and inversely proportional to the resistance of the circuit.

Induction and Magnetism

1821. Historical Note. The discovery in 1832 of the fact that when a conductor is moved in a magnetic field an electromotive force is set up in the conductor is attributed by Ganot to Farady alone, while other authorities attribute it to both Farady and Henry in 1831. This discovery is the foundation of all modern electrical engineering.

1822. Magnets and Magnetic Laws. Magnets are of two kinds, permanent and electro-magnets. Their phenomena of attraction and repulsion being conventionally assumed to be due to lines of force which emanate from or surround the magnet. If iron filings be placed near the poles, that is, in the field of an electromagnet, they arrange themselves in concentric circles and from this it is assumed that the forces may be represented by closed curves termed loops of force.

From the foregoing, Mr. Kent makes the following assumptions concerning the loops of force and a conductive circuit:

(1) That the lines or loops of force in a coiled conductor are parallel to the axis of the conductor.

(2) That the loops of force external to the conductor are proportional in number to the current in the conductor, that is, a definite current generates a definite number of loops of force. These may be stated as the strength of field in proportion to the current.

(3) That the radii of the loops of force are at right angles to the axis of the conductor.

The magnetic force proceeding from a point is equal at all points on the surface of an imaginary sphere described by a given radius about that point. A sphere of radius 1cm has a surface of 4π square centimeters. If F = total field strength, expressed as the number of lines of force emanating from a pole containing M units of magnetic matter,

$$F = 4\pi M; \; M = F \div 4\pi$$

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Magnetic attraction or repulsion emanating from a point varies inversely as the square of the distance from that point. The law of inverse squares, however, is not true when the magnetism proceeds from a surface of appreciable extent and the distances are small as in dynamo-electric machines.

1823. The Strength of Electro-magnets and Solenoids. An electro-magnet is made by coiling a current-carrying conductor around a core of soft iron. A solenoid is generally a uniformly wound, long, straight coil, carrying a current, the current producing a uniform field at its center, though in some special instances, as in some of the electrical instruments, the coil consists of a helix with but a single turn. In discussing the strength of the field Sheldon makes the following remarks: "i being the current and H the uniform field produced at the center, the solenoid may be considered as composed of magnetic shells arranged at equal distances from each other. It takes $4\pi i$ ergs to move a unit magnet pole — one that will repel an equal like pole when at the distance of one centimeter, with the force of one dyne — from one side of a shell to the other; and $4\pi i\, n$ ergs to pass it through n consecutive shells of the solenoid. If these n shells occupy a length on the solenoid of l centimeters, then:

$$\text{Work} = \text{Force} \times \text{Distance} = Hl = 4\pi i\, n \text{ ergs},$$

and the magnetizing force, that is, the strength or intensity of the field in the solenoid is:

$$H = \frac{4\pi i\, n}{10l}.$$

A development of a Tractive formula, according to Foster is, as follows:

If n = number of turns in the coil

I = amperes of current flowing

$$1.257 = \frac{4\pi}{10} \text{ (to reduce to C. G. S. units)}$$

$$\text{Magneto-motive force} = 1.257 \times nI = F$$

$$\phi = \text{Magnetic flux} = \frac{\text{Magneto-motive force } F}{\text{reluctance } R}$$

$$\phi = \frac{F}{R}$$

$$F = \frac{4\pi nI}{10} = \text{(as above) } 1.257\, nI$$

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$$R = \frac{l}{A\mu}$$

$$\phi = \frac{1.257\,nI}{\frac{l}{A\mu}}$$

$$nI = \frac{\phi \frac{l}{A\mu}}{1.257}$$

If dimensions are in inches, and A is in square inches, then

$$nI = \phi \frac{l}{A\mu} \times .3132$$

and $\phi = BA$

(B being the conventional symbol for magnetic flux density or magnetic inductions.) The formula for the *pull* or lifting power of an electro-magnet, in inch measure is,

$$\text{Pull (in pounds)} = \frac{B^2 A}{72{,}134{,}000}$$

TABLE OF MAGNETIZATION AND TRACTION OF ELECTRO-MAGNETS

B Lines per Sq. Inch	Pounds per Sq. Inch	B Lines per Sq. Inch	Pounds per Sq. Inch
6,450	.577	58,050	46.72
12,900	2.308	83,850	97.47
19,350	5.190	109,650	166.6
25,800	9.228	129,000	230.8
32,250	14.39		

FIG. 1823.

DYNAMOS AND GENERATORS

1831. Description of a Dynamo or Generator. A dynamo or generator may be defined as a machine which converts the mechanical energy, generally of rotation, into electrical energy by means of electro-magnetic induction; electrical energy being delivered either in the form of an alternating or direct current. The electricity is not produced by the dynamo, its action being the generation or production of an electro-motive force causing the current to pass through the external circuit. In tracing the analogy between the flow of water and the flow of electricity through the internal and external circuits, we have — in the

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internal circuit the E.M.F. causes the current to flow from a lower to a higher potential just as water is pumped from a lower to a higher level; while in the external circuit, like water flowing from a higher to a lower level, the electricity flows from a higher or positive potential to a lower or negative potential.

The essential parts of a dynamo are the field, the armature and the commutator or collector rings. The field is generally produced by electro-magnets made by winding a number of coils about suitable iron cores. The armature is so designed that the number of lines of force which thread through its loops or coils, from the field, will be constantly varied, resulting in the production of an E.M.F.; it is composed of a number of loops or coils wound about an iron core. The commutator or collector rings are mechanical devices on a shaft for either converting or collecting the current generated in the armature; this current is taken off by means of stationary brushes in sliding contact with the commutator or rings.

Dynamos may be classified according to the current delivered into alternating or direct current; according to mechanical detail into revolving armature with stationary field magnet; stationary armature and revolving field; and both stationary armature and field between which is revolved an iron core; the so-called inductor AC in which the poles are turned inward and carry two windings, the field and the armature with a central toothed inductor revolving in such a way as to increase and decrease the number of lines of force in the field; and according to their winding into separately excited, series-wound, shunt-wound and compound-wound dynamos.

1832. Principles of the Dynamo or Generator. We will now consider the phenomenon occurring when a loop of wire is revolved in a magnetic field about an axis perpendicular to the lines of force.

It is evident from the principle of induction that, as the loop is a conductor whose sides but not ends move across the magnetic field, cutting the lines of force, there will be induced in it an E.M.F. In the simplest form of a bi-polar machine as the loop revolves about its axis, one side is going down while the other is going up, and for this reason the E.M.F.'s induced, though traversing in opposite directions, are on opposite sides of the loop, and therefore instead of neutralizing each other are cumulative,

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that is the two pressures must be added together. The lines of force threading through the loop during the first quarter are gradually decreasing at an increasing rate, and the E.M.F., being dependent upon the *rate of change* of the lines of force through it, reaches a maximum when the loop is in a horizontal position parallel to the lines of force, so that none thread through it. At the end of the next quarter revolution the E.M.F. has again become zero. If we connect each end of the wire loop with slip or collector rings, and the circuit be completed by brushes sliding on them, a current will flow through the system. During the next half of the revolution, that side of the loop that was going down begins to move upward and consequently the direction of

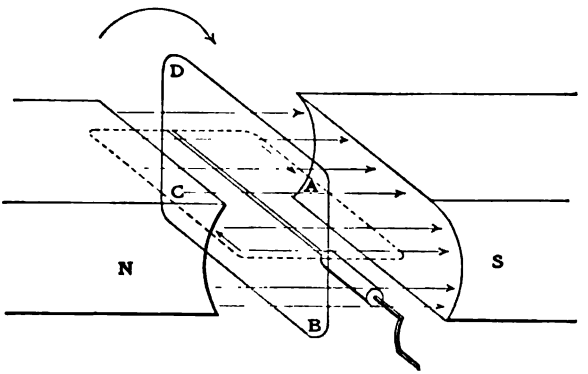

FIG. 1832. — Principle of Dynamo.

the induced electro-motive force will be changed, as will also the direction of the current through the circuit; thus for each revolution we find that the direction of the current has twice been changed, that the current is alternating and that our ideal machine is an alternator or alternating-current machine.

1833. Commutators. If we wish to obtain a direct current from this device, it will be necessary to cut the rings into halves, giving two semicircular pieces, to each of which is attached one end of the loop; these pieces must be insulated from each other. We now have the commutator in its simplest form. If we place the brushes so that, at the instant the induced E.M.F. in the loop changes its direction, the brushes slide across from one segment of the commutator to the other, the current, while reversed in the loop, is left flowing in the same direction in the external

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circuit. Just at the instant of commutation, the induced E.M.F. is zero, as is also the current; this occurring twice every revolution. To obtain a practically constant current, free from these undesirable fluctuations, it will only be necessary to multiply the number of loops and commutator segments. The fluctuations in a bipolar machine having twelve loops and segments is 1.7% of the total E.M.F. If each of the loops of wire were given two turns before being connected to the commutator segment, and the number of revolutions and the strength of field remain the same, twice the E.M.F. will be produced with the same number of commutator segments.

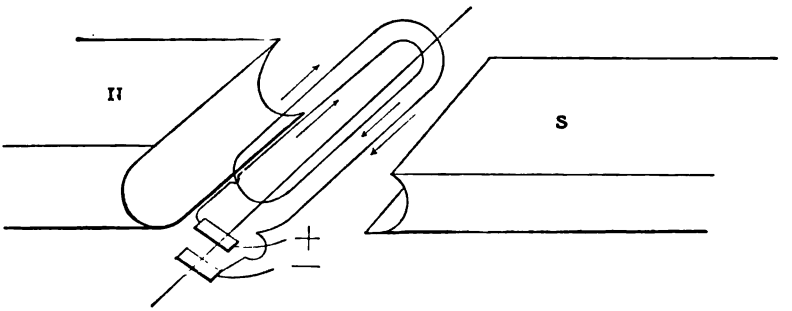

FIG. 1833. — Principle of Commutators.

1834. Armatures. As we have already learned, the armature is that portion of the dynamo in which the E.M.F. is induced by its movement in a magnetic field, and consists of the loops of wire with the necessary insulation, the iron core that sustains them and the minor connecting details. The loops of wire, or conductors in which the E.M.F. is generated, are termed inductors.

Armatures are generally of three kinds, drum, ring and disc. The *drum* armature is one in which both sides of the loop of wire cut the lines of force. The *ring* consists of an annular iron core about which the wire is wound; the lines of force emanating from the north pole of the magnet flowing through the core instead of across the air space inside the ring. Only the wires on the outer periphery of the ring cut the lines of force; those on the inside serving only to complete the electrical circuit. For this reason a greater portion of the wire on this armature is "dead" than on a drum armature.

The *disc* armature, seldom used in this country, is a drum

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armature of large diameter and short length, with the greater portion of the wire exposed to the pole pieces placed at its ends.

1835. Field Magnets. In general, the field magnets of dynamos are electro-magnets and are bi-polar or multi-polar as they possess two or more (an even number of) poles. In the smaller machines, which are usually bi-polar, having one north and one south pole, the armature is revolved between them; while the larger machines, usually multi-polar, have the north and south poles arranged in a circle with their faces concentric with the armature. The different methods of arranging the coils of both bi-polar and multi-polar machines are illustrated in the following figures. Figs. 1835*a*, *b*, *c*, *d*, *e*.

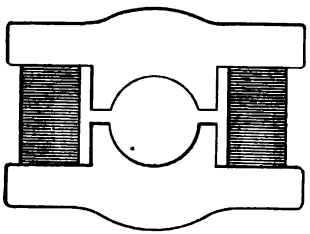

FIG. 1835*a*.

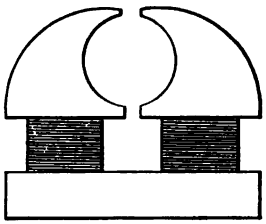

FIG. 1835*b*.

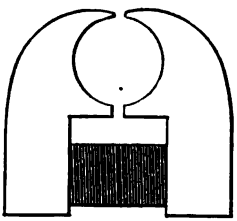

FIG. 1835*c*.

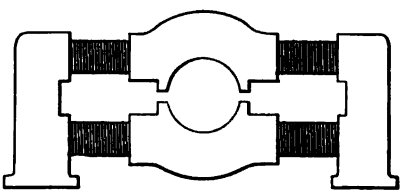

FIG. 1835*d*.

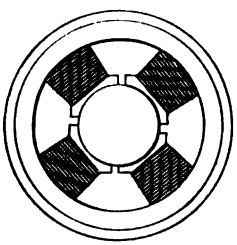

FIG. 1835*e*.

1836. Windings. The following description of the various windings of field magnets is taken in part from Kent and Sheldon.

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Separately Excited. The field magnet coils in this class of dynamos have no connection with the armature coils but receive their current from a separate machine or source.

Series Wound (for varying load). In this class of dynamos, the field winding and the external circuit are connected in series with the armature winding so that the entire armature current must pass through the field coils. Since, in the series-wound dynamo the armature coils, the field and the external circuit are in series, any increase in the resistance of the external circuit will decrease the electro-motive force from the decrease in the magnetizing currents. A decrease in the resistance of the external circuit will, in a like manner, increase the electro-motive force from the increase in the magnetizing current. The use of a regulator avoids these changes in the electro-motive force.

Shunt Wound (for constant speed). In this class of dynamos the field magnet coils are placed in a shunt to the armature circuit, so that only a portion of the current generated passes through the field magnet coil, but all the difference of potential of the armature acts at the terminal of the field circuit. In a shunt-wound dynamo an increase in the resistance of the external circuit increases the electro-motive force; and a decrease in the resistance of the external circuit decreases the electro-motive force. This is just the reverse of the series-wound dynamo.

In a shunt-wound dynamo a continuous balancing of current occurs, the current dividing at the brushes between the field and the external circuit in inverse proportion to the resistance of these circuits. If the resistance of the external circuit becomes greater, a proportionately greater current passes through the field magnets, and so causes the electro-motive force to become greater. If, on the contrary, the resistance of the external circuit decreases, less current passes through the field and the electro-motive force is proportionately decreased.

Compound Wound. In this class of dynamos the field magnets are wound with two separate coils, one of which is in series with the armature and the external circuit and the other in shunt with the armature.

Efficiency. The efficiency, at full load, of standard belted motors and generators varies from 81% in a 1-kilowatt generator, 87% in a 10-kilowatt, 92% in a 75-kilowatt, to 93% in a 225-kilowatt generator.

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CHAPTER XIX

POWER TRANSMISSION

Electric Transmission

1911. Efficiency of Electric Systems. The mechanical efficiency of any system is the ratio existing between the power delivered to the generator and the power delivered by the motor at the end of the transmission system. The commercial efficiency of a system will vary with the load; however, it is reasonable to expect, under favorable conditions, a loss of from 8% to 10% at the generator with a like loss at the motor. The loss in transmission or "drop" is due to the fall in pressure, is governed by the size of the wires, and for long-distance transmission varies from 4% upward. With the present-day apparatus, the practical efficiency of a long-distance transmission system is considered to be from 72% to 82%. The longest system known at the present writing is that of the Standard Electric Transmission Co., of California. The power is transmitted a distance of two hundred and fifteen miles and it is stated that the over-all efficiency of this transmission measured to the receiving step down transformers at the terminus was as high, at full load, as 80%.

There are three general methods of electric transmission: (1) The direct-current system. (2) The alternating-current system. (3) The motor-dynamo or regenerating system.

1912. Governing Conditions in the Selection of Systems. The factors or conditions which govern the selection of any system are divided by F. R. Hart into those that are fixed and those that are variable as follows: the fixed conditions being (1) The capacity or source of the power. (2) The cost of power at the source. (3) The cost of power by other means at the point of delivery. (4) Danger considerations at the motor. (5) Operating conditions. (6) Construction difficulties arising from length of the line and topography of the country. The variable or partially variable factors are: (7) The power and efficiency of

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the system. (8) The number and size of the delivery units. (9) The initial voltage. (10) The pounds of copper on the line. (11) Original cost of construction and equipment. (12) Gross expenses, operation, depreciation, etc. (13) Liability of trouble and stoppage. (14) Danger at station and on line. (15) Convenience in operation, making changes, extension, etc.

On the assumption that the station equipment will be approximately a constant, whatever the initial pressure may be, the great variation in the cost of wire at different pressures is shown by Mr. Hart in the following table (Fig. 1913*a*) in which he gives the weight of copper required for transmitting 100 horse-power 5 miles.

1913. Tabulated Transmission Data.

WEIGHT OF COPPER WIRE REQUIRED TO TRANSMIT 100 H. P. 5 MILES

Voltage	Drop 10%	Drop 20%
2,000	16,800 Lbs.	8,400 Lbs.
3,000	7,400 "	3,700 "
10,000	620 "	310 "

FIG. 1913*a*.

The subdivisions of each of the general methods of transmission are tabulated by Kent as follows:

- Continuous Current.
  - 2-Wire.
    - Low Voltage.
      - One Machine.
      - Machines in Parallel.
    - High Voltage.
      - One Machine.
      - Machines in Parallel.
      - Machines in Series.
  - 3-Wire.
    - 2 Machines in Series.
    - Machines in Multiple Series.
  - Multiple Wire.
    - Machines in Series.
- Alternating Current.
  - Alternating Single Phase.
    - Without Conversions.
    - With Conversions.
  - Alternating Multi-Phase.
    - Without Conversions.
    - With Conversions

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Regenerating Systems.	Alternating Continuous.
	Alternating Converter; Line Converter; Alternating Continuous.
	Continuous-Continuous.
	Partial Re-conversion of any system.

The relative advantages of these systems vary with each particular transmission problem, but in a general way may be tabulated as follows:

	System		Advantages	Disadvantages
Continuous	2-Wire { Low Voltage		Safety, Simplicity.	Expense for Copper.
	2-Wire { High Voltage		Economy, Simplicity.	Danger, Difficulty of Building Machines.
	3-Wire		Low Voltage on Machine and Saving in Copper.	Not Saving Enough in Copper for long Distances. Necessity for "Balanced" System.
	Multiple Wire.		Low Voltage at Machines and Saving in Copper.	
Alternating	Single Phase.	May be Transformed into Direct Current	Economy of Copper.	Cannot start under Load. Low Efficiency.
	Multiple Phase.		Economy of Copper, Synchronous Speed Unnecessary, Applicable to very long Distances.	Requires more than 2 Wires.
	Motor-Dynamo.		High Voltage Transmission. Low Voltage Delivery.	Expensive, Low Efficiency.

FIG. 1913*b*.

Note. Single-phase motors are now made of various patterns which can start under full load, such as Wagner, Century, Westinghouse Compensated Series Motor, General Electric, etc. It is true that such a motor must be larger and more expensive than a polyphase; it need not be less efficient except so far as one considers weight a factor in determining efficiency.

1914. Systems of Electrical Distribution in Common Use. In a paper before the Engineering Society of Western Pennsylvania, Chas. T. Scott ably discusses the various systems of electrical distribution. The following table is abstracted from this paper:

1. Continuous or Direct Current.
   A. Constant Potential.

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110 Volts — distances less than, say, 1500 feet.
For incandescent lamps.
for arc lamps, usually 2 in series.
for motors.
220 Volts — distances less than, say, 3000 feet.
for incandescent lamps, usually 2 in series.
For arc lamps, usually 4 in series.
For motors.
220 Volts, 3-Wire — distances less than, say, 3000 feet.
For incandescent lamps.
For arc lamps, usually 2 in series on each branch.
For motors; 110 or 220 volts, usually 220 volts.
500 Volts — distances less than, say, 8000 feet.
For incandescent lamps; usually 5 in series.
For arc lamps, usually 10 in series.
For motors, stationary and street car.

B. Constant Current.
Usually about 6.6[1] amperes, the volts increasing to several thousand as demanded.
For arc lamps.

[1] Though formerly used for motors, now seldom used on account of power limit and danger from excessive voltage.

2. Alternating Current.
A. Constant Potential.
For incandescent lamps.
For arc lamps.
For small motors.
Multi-phase systems.
For lighting.
For motors.
For rotary transformers for giving direct current.

B. Constant Current.
Usually 10 amperes.
For arc lamps.

1915. Motors, Discussion and Principles. In general, what has been said with reference to the principles of the direct-current dynamo applies to the motor; in fact, it is the same machine with the nature of its operation reversed. In the motor the

[1] Rewritten to conform with present practice.

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electrical energy of the current is transformed into the mechanical energy of rotation; in the dynamo only one electro-motive force exists, whereas in the motor there must always be two. There is no difference between the action of the motor armature and the dynamo armature as they revolve in the fields. For the same speed and the same current, the same amount of E.M.F. will be generated in the motor as in the dynamo; the direction of this counter E.M.F., however, tends to send the current in the opposite direction.

The relation and equations are explained as follows by Prof. F. B. Crocker:

1 kilowatt dynamo $I = E \div R$; 10 amperes = 100 volts $\div$ 10 ohms.

1 kilowatt motor $I = \frac{E - e}{R_1}$; 10 amperes $= \frac{100 \text{ volts} - 90 \text{ volts}}{1 \text{ ohm}}$.

I is the current; E the direct E.M.F.; e the counter E.M.F.; R, the total resistance of the circuit; and R_1 the resistance of the armature. The current and direct E.M.F. are the same in the two cases, but the resistance is only $\frac{1}{10}$ as much in the case of the motor, the difference being replaced by the counter E.M.F., which acts like resistance to reduce the current. In the case of the motor, the counter E.M.F. represents the amount of the electrical energy converted into mechanical energy. The so-called electrical efficiency or conversion factor = counter E.M.F. $\div$ direct E.M.F. The actual or commercial efficiency is somewhat less than this owing to friction, Foucault currents, hysteresis, etc.

The work of a motor depends on the product of two factors, torque and speed. The torque, which is the twisting moment or effort of the armature, is measured in foot-pounds and is found by multiplying the radius of the armature pulley in feet by the pounds pull on the belt. Torque may be measured directly as the force in pounds at one foot radius, *i.e.*, the pull on a belt running on a pulley 2 feet in diameter.

In general, the conditions under which motors operate may be divided as follows: (1) Those operating at a constant-speed and variable torque; best adapted for this purpose are the ordinary direct-current shunt-wound motors which operate on constant-potential circuits — the work of driving a line shaft being typical, for a constant speed must be maintained regardless of the number of machines in operation. (2) Those which operate

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at a variable speed with a constant torque; best adapted for these conditions are the series-wound motors operating on constant-potential circuits, their typical service being the driving of cranes, hoists and elevators where a constant load is operated at a variable speed. (3) Those which operate at a variable speed with a variable torque; best adapted for these conditions is the series-wound motor operating on a constant-potential circuit — the typical conditions being found in the operation of street railway motors, where in starting the torque is at maximum while the speed is at minimum, and where, as the car gains headway, the torque diminishes as the speed increases. Many series motors for trolley cars are so wound as to have a saturated field at practically all speeds, so that variations of current do not cause variations of speed. If field varies as current, then torque varies as square of current, which causes too rapid a falling off in torque as speed increases.

On the direct-current circuits, the characteristic action of the series-wound motor is to build up the field and the output as the load increases; whereas in the shunt-wound motor the field strength falls as the load increases — the compound winding being much used to operate textile machinery where any slight variation in the speed would affect the character of the product. The reader is referred to Chapter XX, on Motor Drives, etc., where much recent additional information may be found regarding motors, their application and regulation.

1916. Motor Speed Regulation. The accepted methods of regulating motor speed are, by inserting resistance in the armature of shunt-wound motors; by varying the field strength of series-wound motors; and by switching sections of the field coils in or out of circuit. Field regulation is now an accepted practice with shunt-wound motors for controlling speed. As great a variation as 6 to 1 can be thus obtained, giving full power at all speeds. Additional information regarding motor speed regulation may be found in Chapter XX — Motor Drives and Motor Driven Machine Tools.

1917. Alternating-current Motors. The majority of the alternating-current motors in common use may be divided into two classes, viz., synchronous and induction motors. If any alternator be brought into synchronism with the alternator generating the current, it may be used as a motor, the action of the two being similiar to the action of two generators in parallel.

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1918. Synchronous Motors. Synchronous motors are almost identical in construction with the driving alternator, operate on single or polyphase systems, and consist of two essential parts, the field and the armature, either of which may revolve. The field of synchronous motors must be excited in the same way as the alternator, by a separate, continuous current. The drawback to those operating on a single phase being that they are not self-starting but must be brought into synchronism with the alternator by some external means.

Polyphase motors, however, are self-starting, that is, with no load. It is better to bring them to speed by independent means on account of the large current necessary to start them. Such machines are usually started by a small induction motor; or in such as have the field excited by a small direct-current generator belted to the motor, by operating this generator as a motor to start.

The effect of weakening the field of a direct-current motor is to increase the speed, while the current flowing through the armature remains practically unchanged. No such change of speed occurs if the field strength of a synchronous motor be changed, for such a motor has to keep step with the alternator. The adjustment to the changes of load and field strength being effected in such a motor by changing the phase difference between the current and the E.M.F. As the load varies, the current in the motor either leads or lags behind the E.M.F. and the E.M.F. will no longer be in opposition to that of the alternator, resulting in a constant flow of current sufficiently large to enable the motor to carry its load. When the machine is too much overloaded, this lagging of one armature behind the other becomes sufficiently great to throw the motor out of synchronism, that is, to fall out of phase with the generator and cause it to stop.

For economy in operation, synchronous and induction motors are sometimes placed in the same circuit. In such an arrangement the synchronous motor may be made, by increasing the field excitation, to cause the current to lead, while the induction motor causes it to lag; this balancing effect being conducive of efficiency. Synchronous motors are best adapted for power transmission plants and for large power units of high voltage, with a constant load and speed. The drawbacks to this class of motors are the necessity of excitation and the inability to start.

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1919. Induction Motors. Induction motors are sometimes made to operate on single-phase circuits, but they are more generally operated on two- or three-phase circuits. The two essential parts of an induction motor, either of which may revolve, are the primary or field which is connected with the line, and the secondary or armature in which are induced the currents by the primary.

Comparing the action of the two motors, we have the current led into the armature from the line in a synchronous or in a direct-current motor, the reaction of these currents upon the fixed field producing the motion; while with the induction motor the current is led from the line into the field to produce a magnetic field which constantly changes or rotates and which induces

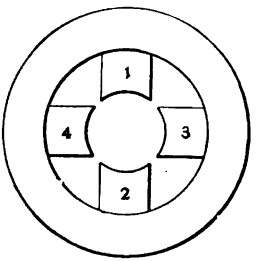

FIG. 1919. — Rotating Field.

currents in the armature coils. The reaction of these induced currents on the field results in motion — in most cases of the armature — hence the name induction motors.

The rotating field being distinctive of the induction motor, we will consider its action on a two-phase circuit with a four-pole field:

The poles 1 and 2 (Fig. 1919) are wound from one of the pairs of wires while 3 and 4 are wound free from the other; the two-phase being 90° apart. At the instant that 1 and 2 are receiving a maximum current, 3 and 4 are demagnetized. As the cycle progresses, the magnetism of 1 and 2 decreases while that of 3 and 4 increases, resulting in a shifting or rotation of the field area of maximum intensity. It must be understood that the rotating refers to this shifting of the field rather than to any motion or revolution of the primary. The armature within this field rotates simply by the shifting effect without the use of collector rings; the

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revolving part is termed the rotor and the stationary part of the motor the stator, and in order that such a motor may carry a load some slip is necessary so that the conductors in the rotor may cut lines of force and induce currents. The greatest torque is exercised when such a motor is standing still and is directly, as is the output, proportional to the square of the pressure in the primary; the minimum torque being when running in synchronism with the rotating field.

The induction motor, it will be seen, possesses most of the advantages of the direct-current motor, in that it has a large starting torque and may be started and stopped frequently; also, when overloaded the induction motor will slow down until the induced currents in the armature are sufficient to carry the load.

Compressed Air Transmission

1921. Compressed Air. The following discussion of the thermodynamics of air compression is taken in part from a treatise on the physical properties of gases by Kimball.

All the work which is required to compress air is converted into heat, as is evidenced by the rise in temperature of the compressed gas. In practice, many devices are employed to carry off the heat as fast as it is developed, in order that the temperature may be kept down. It is not possible, however, in any way to totally remove this difficulty. The question may arise whether, if all the work done in compression is converted into heat and this heat gotten rid of as rapidly as possible, the work is not virtually thrown away and the compressed air possesses really no more energy than it had before compression. If the temperature is no higher, it is true that the compressed gas has no more energy than is had before compression, but the advantage of compression lies in bringing its energy into a more available form. The total energy of the compressed air and uncompressed gas is the same at the same temperature; however, the available energy is much greater in the former. Whenever compressed air performs work in driving machinery, it gives up energy equal in amount to the work performed and its temperature is thereby greatly reduced. Zahner, in his work on "Transmission of Power by Compressed Air," concludes that, since the compression of air always develops heat and that, as this compressed air is always allowed to cool down to the temperature of the surrounding atmosphere before

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it is used, the mechanical equivalent of this dissipated heat is lost. This loss is unavoidable.

As the heat of compression increases the volume of the air, it is necessary to carry it to a higher pressure in the compressor in order that we may finally have a given volume of air at a given pressure and at the temperature of the surrounding atmosphere. The work expended in securing this excess of pressure is also lost.

Another source of loss of energy in a compressed-air system is the friction of the air in the pipes, leakage, dead spaces, the resistance offered by insufficient valve area and the valves, inferior workmanship and slovenly attendance.

In the adiabatic compression of air, all the heat resulting from the compression is retained in the compressed air, while in the isothermal compression of air the heat is removed as rapidly as produced by means of some form of refrigerator.

That energy which a fluid or gas is capable of exerting against a piston in changing from a given volume and temperature to a total privation of heat and indefinite expansion is termed its intrinsic energy.

1922. Air Compressors. A detailed description of any one of the hundreds of different air compressors on the market is deemed unnecessary; it being sufficient to state that in principle the simple air compressor is an air pump consisting of a cylinder with suitable inlet and outlet valves in which a piston operates, first to draw into the cylinder through the inlet valve a certain quantity of air, and next to compress this air to a certain pressure and to force it through the outlet valves into the receiver, which latter is usually a tank.

1923. Compressed-air Engines and Machines. The compressed-air engines on the market, as well as other compressed-air machinery, vary widely in detail and design, according to the work to be performed and the ideas of the manufacturer. It may be stated, however, that most of the air engines and tools, like steam engines, have reciprocating pistons, valves and parts, and the air is used in much the same way that steam is used in steam engines. Compressed air is used extensively in mining operations, not only for driving hoisting engines, rock drills and underground pumps, but for operating the locomotives as well. Where compressed air is used to drive machines in mines and tunnels, the loss of power in common practice is about 70%; the

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best practice having a loss of about 60%. In the machine shop, compressed air is being widely used for operating pneumatic hammers, drills and riveters; for air hoists and light cranes and for cleaning castings and machines. Compressed air is used to furnish the blast for various furnaces, cupolas, etc. When so used the pressures are comparatively low and some form of blower is generally employed, the pressure varying from a few ounces to three quarters of a pound. Compressed air is also used for pneumatic tube service in which small carriers are forced through smooth tubes.

Hydraulic Transmission

1931. Adaptability and Uses. When the moving of very heavy loads at low velocities is to be effected, water under a pressure generally of from 700 to 2000 pounds per square inch affords an efficient method of transmitting power to a distance, the application being the operation of elevators, cranes, presses, lifting-jacks and similar machinery. The system usually consists of one or more pumps capable of developing the required pressure; accumulators, which are vertical cylinders with heavily weighted plungers passing through stuffing boxes in the other end, by means of which a quantity of water is accumulated at the pressure to which the plunger is weighted; the distributing pipes and the machinery to be operated.

1932. Hydraulic Forging. One of the important uses of hydraulic power transmission is in the operation of heavy forging machines for the compression of steel ingots while in a fluid state; the operation of hammers, flanging, and forging presses and riveting machines. For the production of massive steel forging, the hydraulic forging press has superseded the steam hammer. When a steam hammer was employed for this purpose, it was noted that the external surface of the ingot absorbed a large proportion of the sudden impact of the blow and that only a comparatively small effect was produced at the central portions of the ingot, this being due to the resistance offered by the inertia of the mass to the rapid motion of the falling hammer. This disadvantage is entirely eliminated by the slow, though powerful, compression effected by the hydraulic forging press.

Some idea of the size of hydraulic forging presses and also the extent to which they are used may be gained from the state-

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ment that a forging press has been designed by John Fritz for the Bethlehem Works, of 14,000 tons capacity, to be run by engines and pumps of 15,000 horse-power. The plant is served by 4 open-hearth steel furnaces of a united capacity of 120 tons of steel per heat.

The efficiency of a hydraulic apparatus of direct plunger or ram type varies from 92% to 94%.

Rope Transmission

1941. Wire Rope Transmission. Where large powers are to be transmitted over rough ground or waterways to a distance not exceeding two or three miles, wire-rope transmission is sometimes best adapted to the conditions which obtain. The rope, generally made of fine steel wire, is usually composed of 7, 12 or 19 wires and operates in the transmission in the same way that a belt does. The sheaves (rope wheels) are usually made strong, as light as possible and of cast iron. The bottom of the groove in which the rope runs is filled with various substances, such as jute yarn, tarred oakum, hard wood, leather and rubber; a very satisfactory filling being composed of segments of leather and blocks of India rubber, soaked in tar, packed alternately in the groove. The maximum distance between sheave towers, the sheaves being 10 feet in diameter, is given by Kent as 600 feet, though an exceptional drive at Lockport, N. Y., has a clear span of 1700 feet.

It is customary to transmit the power with the lower portion of the rope, as the greatest deflection usually occurs in this portion when idle. Practice demonstrates that the life of a rope is longest when the bending over sheaves is all in one direction, and when the sheave diameter is large, that is, over 100 rope diameters for steel and 180 for iron wire.

In some transmissions, instead of grooved drums or a number of sheaves about which the rope makes two or more laps, grip pulleys are sometimes used. The rims of such pulleys are fitted with a continuous series of steel jaws which bite the rope in contact by reason of the pressure against them, releasing it as soon as the pressure is relieved and offering free egress to the rope.

1942. Rope Driving. In mills and factories where the power is large and the distance it is to be transmitted comparatively

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great, rope drives compare favorably with the shafting, belting and gearing system and for a certain class of work are rapidly superseding them, owing to the former's higher efficiency and greater flexibility. The advantages and applications of such a system become apparent when we consider that a perfect alignment of sheaves is unnecessary, that the shafts may be placed at any angle with each other and at any reasonable distance apart; in fact, it would be difficult to conceive of a combination of shafting and pulleys as to angles and position that would not lend itself readily to a rope drive.

1943. Systems. In practice, there are two systems of rope drives, namely, the multiple and the continuous systems. In the

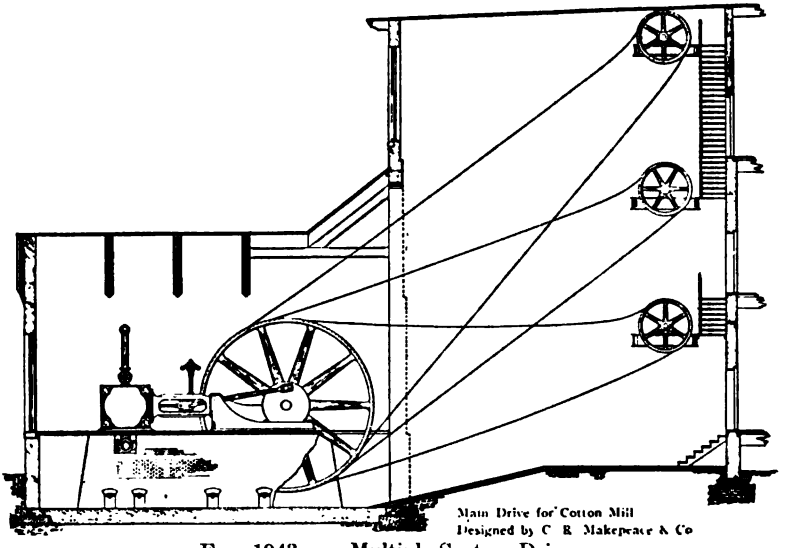

FIG. 1943*a*. — Multiple System Drive.

multiple system a number of single, independent rope belts run side by side, each being spliced on the pulleys very taut and running until the stretching is sufficient to make them slip when they are re-spliced. In the continuous system, a single rope is wound around the grooved pulleys several turns, enough times to transmit the required power; and a tension pulley, to give the necessary adhesion, is placed where it will take care of the slack at the point at which it naturally accumulates. Generally, the

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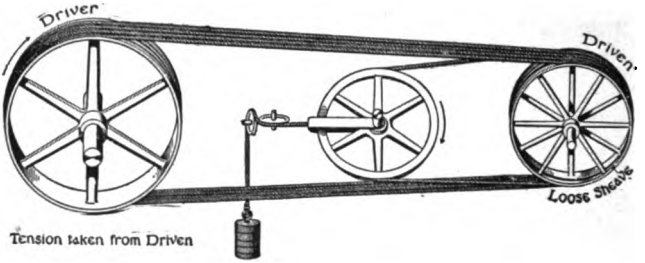

FIG. 1943*b*. — Continuous System, Horizontal Drive.

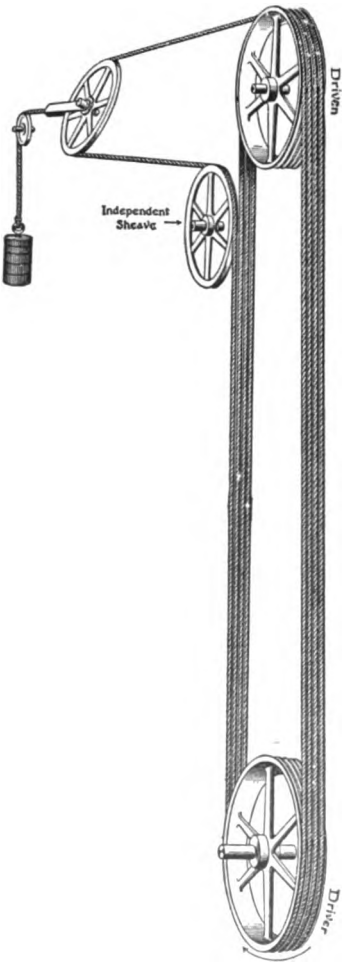

FIG. 1943*c*. — Continous System, Vertical Drive. Tension taken at Driven.

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last strand from the driver leads over an idler sheave, mounted at the side of or near the driven pulley, to the tension pulley, from which it is returned to the groove on the opposite side of the driven pulley.

1944. Sheaves and Pulleys. A sheave wheel or pulley is one made of cast iron, in the rim of which are formed deep grooves of suitable shape to receive the turns of the rope. If several grooves are cut in one pulley, they must all be of the same shape,

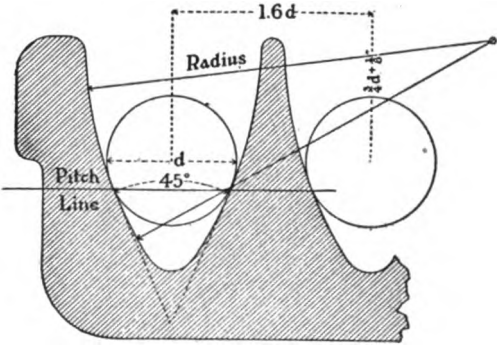

FIG. 1944*a*. — Standard Drive Groove.

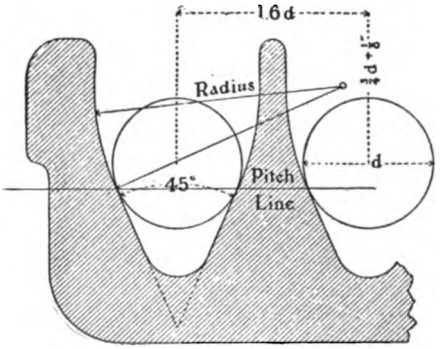

FIG. 1944*b*. — Straight-side Drive Groove.

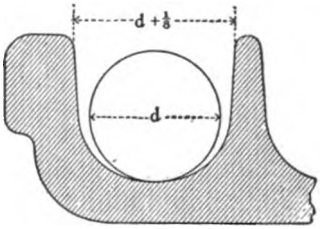

FIG. 1944*c*. — Idler Groove.

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size and diameter at the pitch line, in order to prevent creeping or slippage, either of which results in an undue straining of certain portions of the drive. The contour of a groove of accepted form is shown in Fig. 1944*a*, the sides being curved. The "Engineer's Standard Grooves," designed by the Jones & Laughlin Steel Co., are nine in number, and though similar to the shape shown in Fig. 1944*a*, are not in accordance with the proportions given. Fig. 1944*b* is a form sometimes used but is not as good as that shown in 1944*a*. Tangents to the side at the pitch line are at an angle of 45°. The sides are so shaped that the rope in wedging on them results in the production of a high frictional resistance to slipping. The concave sides cause a rolling motion in the rope, which is beneficial in its production of a uniform wear. In practice, the surfaces of the grooves should be carefully polished, as any roughness, due to the tool-marks or imperfections in the casting, rapidly cuts the rope.

The shape of the groove in the idler pulley, as will be seen in Fig. 1944*c*, is semicircular at the bottom with a radius slightly larger than the radius of the rope. In the following table (Fig. 1944*d*), taken for the most part from American Mfg. Co's "Blue Book," will be found some useful data relative to both pulleys and ropes.

DATA RELATIVE TO MANILA TRANSMISSION ROPE AND SHEAVES

Diameter of Rope in Inches	Square of Diameter	Approximate Weight per Foot, Pounds	Breaking Strength, Pounds	Maximum Allowable Tension, Pounds	Length of Splice in Feet			Smallest Diameter of Sheaves in Inches	Maximum Number of Revolutions per Minute
					3-Strand	4-Strand	6-Strand		
½	.25	.12	1750	50	6			20	1060
⅝	.3906	.16	2730	80	6			24	970
¾	.5625	.20	3950	112	6	8		27	760
⅞	.7656	.26	5400	153	6	8		32	650
1	1.	.34	7000	200	7	10	14	36	570
1⅛	1.2656	.43	8900	253	7	10	16	40	510
1¼	1.5625	.53	10,900	312	7	10	16	45.	460
1½	2.25	.77	15,700	450	8	12	18	54	380
1¾	3.0625	1.04	21,400	612	8	12	18	63	330
2	4.	1.36	28,000	800	9	14	20	72	290
2¼	5.0625	1.73	35,400	1012	9	14	20	81	255
2½	6.25	2.13	43,700	1250	10	16	22	90	230

FIG. 1944*d*.

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With a given velocity of the driving rope, the weight of rope required for transmitting a given horse-power is the same, no matter what size rope is adopted. The smaller rope will require more parts but the weight will be the same.

1945. Transmission Rope. The material most suited for transmission rope is the best grade of cotton and manila. Trans-

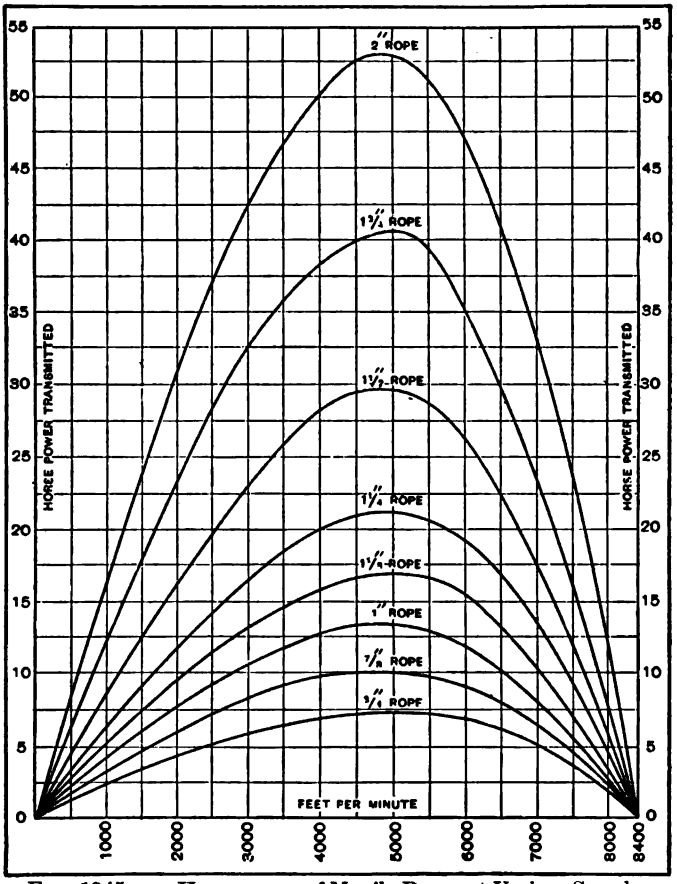

FIG. 1945*a*. — Horse-power of Manila Ropes at Various Speeds.

mission rope of manila is generally made of 3, 4 and 6 strands; the 4 and 6 strand ropes having a central core around which the other strands are laid.

Cotton rope is used largely for service which operates on

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Diameter of Rope	Velocity, Feet per Minute										
	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
¼	2.3	3.3	4.3	5.2	6.0	6.6	7.2	7.3	7.4	7.3	6.9
⅜	3.0	4.5	5.9	7.0	8.2	9.0	9.6	9.8	10.0	9.6	9.0
1	4.0	5.9	7.7	9.2	10.6	11.8	12.7	12.9	13.0	12.7	12.0
1⅛	5.0	7.5	9.7	11.6	13.5	14.9	16.0	16.3	16.7	16.5	15.3
1¼	6.3	9.1	12.0	14.3	16.7	18.5	20.0	20.2	20.7	20.1	18.9
1½	9.0	13.5	17.4	20.7	23.0	26.3	28.7	29.0	29.5	28.6	26.7
1¾	12.3	18.0	23.6	28.2	32.7	36.4	38.5	39.4	40.5	38.7	36.0
2	16.0	23.2	30.6	36.8	42.5	46.7	50.0	51.7	52.8	50.6	47.3
2¼	20.0	29.6	38.6	46.6	53.6	59.2	63.6	65.8	66.3	64.4	60.3
2½	25 0	36.6	47.7	57.5	66.0	71.2	78.0	80.0	81.0	79.0	73.8

FIG. 1945*b*. — Horse-power of Manila Ropes at Various Speeds.

sheaves of small diameter; it is more expensive, less durable, has less strength and is harder to splice than the manila rope.

The wear on transmission rope is both external and internal. The external is caused by the slipping and wedging in the grooves of the pulley; while the internal is caused by the movement of the fibers on each other under pressure in bending over the sheaves. In ordinary practice the wear is assumed to be directly proportional to the speed. Transmission rope manufacturers seek to lessen internal wear by the free use of such lubricants as graphite and tallow on the core and inner strands of the rope.

The foregoing diagram (Fig. 1945*a*) and table (Fig. 1945*b*) give the horse-power of manila ropes at various speeds and are calculated on the basis of a maximum strain of two hundred pounds for a rope one inch in diameter. It will be readily seen that the maximum power, under these conditions, is transmitted at a speed of about 80 feet per second; at higher speeds, the power falls off rapidly because of the excessive centrifugal force.

1946. Splicing. The splicing of a transmission rope is an important matter; the points on which the success of the splice, and incidentally the drive, depend being the length of the splice, which in turn depends upon the diameter of the rope and which is given in the table (Fig. 1944*d*); the diameter of the splice, which should be the same as the diameter of the rope; the securing of the ends of the strands of the splice, which must be so fastened that they will not wear or whip out or cause the overlying strands to wear unduly; and the workmanship of the splice,

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which should be the best it is possible to secure. When splicing an old and a new piece of rope, the new piece should be thoroughly stretched for, at best, it is an exceedingly difficult task on account of the stretch and difference in diameter of the rope.

The illustrations and instructions for making standard rope splices are taken, by the courtesy of the American Manufacturing Co., from their "Blue Book of Rope Transmission."

There are many different splices now in use, but the one that experience has proved best is what is known as the English transmission splice. In describing this we take for our example a four-strand rope, $1\frac{3}{4}$" in diameter, as spliced on sheaves in the multiple sys-

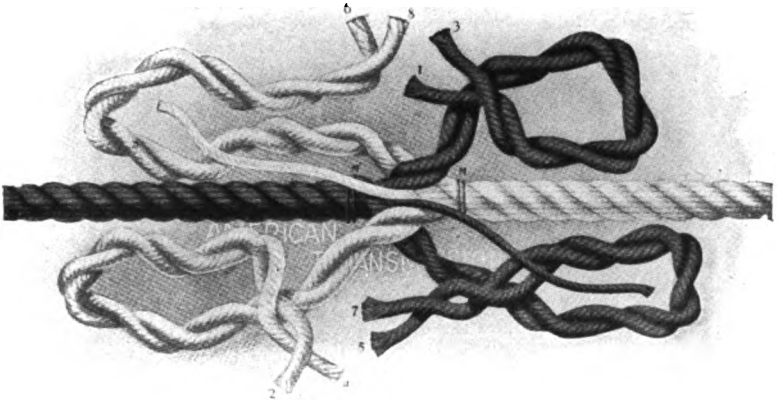

FIG. 1946*a*.

tem. The rope is first placed around sheaves, and, with a tackle, stretched and hauled taut; the ends should pass each other from six to seven feet, the passing point being marked with twine on each rope. The rope is then slipped from the sheaves and allowed to rest on shafts, to give sufficient slack for making the splice.

Unlay the strands in pairs as far back as the twines *M*, *M'*, crotch the four pairs of strands thus opened (Fig. 1946*a*), cores having been drawn out together on the upper side. Then, having removed marking twine *M*, unlay the two strands 6 and 8, still in pairs, back a distance of two feet, to *A;* the strands 1 and 3, also in pairs, being carefully laid in their place. Next unlay the strands 5 and 7 in pairs, to *A'*, replacing them as before with 2 and 4. The rope is now as shown in Fig. 1946*b*. The pair of strands 6 and 8 are now separated, and 8 unlaid four feet back

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to *B*, a distance of six feet from center, strand 6 being left at *A*. The pair of strands 1 and 3 having been separated, 3 is left at *A*, as companion for 6, strand 1 being carefully laid in place of strand 8 until they meet at point *B*. The two pairs of strands 2–4 and 5–7 are now separated and laid in the same manner, every care being taken, while thus putting the rope together, that original twist and lay of strand is maintained. The protruding cores are now cut off so that the ends, when pushed back in rope, butt together.

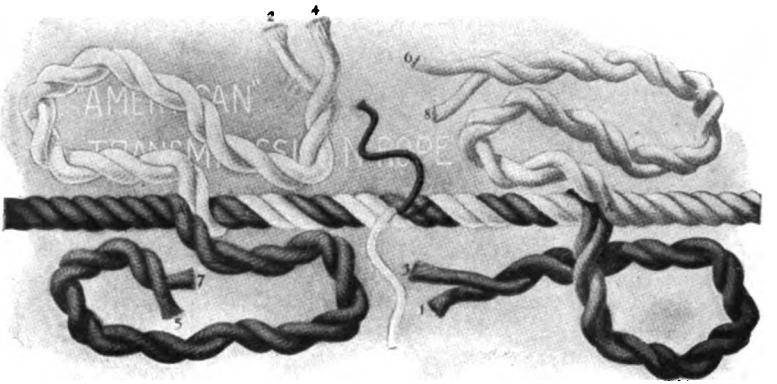

FIG. 1946*b*.

The rope now appears as shown in Fig. 1946*c*, and after the eight strands have been cut to convenient working lengths (about two feet), the companion strands are ready to be fastened together

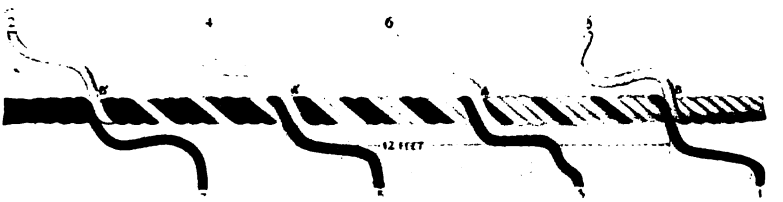

FIG. 1946*c*.

and "tucked"; this operation is described for strands 2 and 7, the method being identical for the other three pairs. Unlay 2 and 7 for about twelve to fourteen inches, divide each strand

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in half by removing its cover yarns (see Fig. 1946*d*), whip with twine the ends of interior yarns 2′ and 7′; then, leaving cover 2, relay 2′ until near 7 and 7′, here join with simple knot 2′ and 7′, Fig. 1946*e*. Divide cover yarns 7, and pass 2′ through them, continuing on through the rope *under* the two adjacent strands, avoiding the core, thus locking 2′, Fig. 1946*f*. *In no event pass* 2′

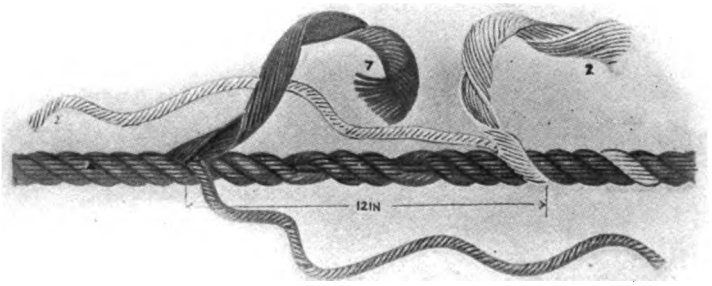

FIG. 1946*d*.

over these or any other strands. Half-strand 7′ must now be taken care of; at the right of the knot made with 2′ and 7′, 2′ is slightly raised with a marlin spike, and 7′ passed or tucked around it two or three times, these two half-strands forming in this way a

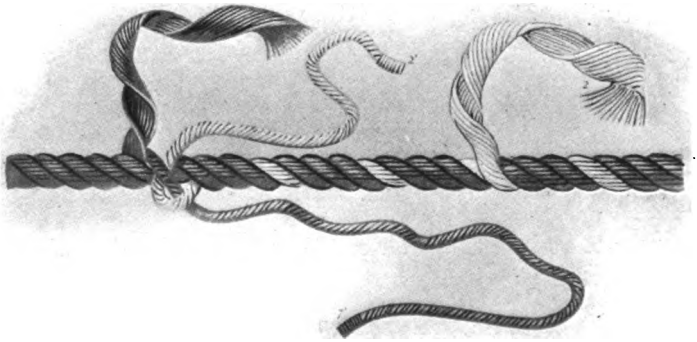

FIG. 1946*e*.

whole strand. Half-strand 7′ is tucked until cover 2 is reached, whose yarns are divided and 7′ passed through them and drawn under the two adjacent strands, forming again the lock. The strand ends at both locks are now cut off, leaving about two

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inches, so that the yarns may draw slightly without unlocking. This completes the joining of one pair of strands, Fig. 1946*g*. The three remaining pairs of strands are joined in the same manner.

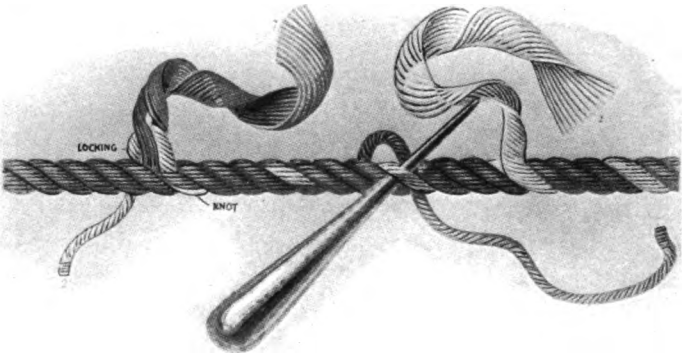

FIG. 1946*f*.

After the rope has been in service a few days, the projecting ends at locks wear away, and if tucks have been carefully made, and the original twist of yarns preserved, the diameter of the

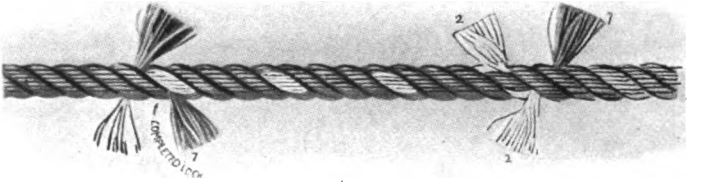

FIG. 1946*g*.

rope will not be increased, nor can the splice be located when the rope is in motion.

SHAFT, PULLEY AND BELT TRANSMISSION

1951. Shafting. With the exception of engine and special shafting, almost all of the shafting in use to-day is manufactured from mild steel, it being finished round, true and smooth, either by cold rolling, turning or grinding. The final sizing of turned shafting is made by passing a hollow tool over it. As the shafting

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is usually made from commercial stock, the sizes run $\frac{1}{16}''$ under that of the bar, that is $1\frac{1}{16}''$, $1\frac{5}{16}''$ and $2\frac{3}{16}''$.

In calculating the strength of shafts, two things must be considered, the resistance to torsion or twisting and the resistance to bending. With reference to the kind of stress to which they are subjected, shafts may be classified, according to the predominating stress, into those subject chiefly to torsion or twisting stresses, such as shafting in general and line shafting in mills and shops; those subject to bending action such as studs or axles of gears; and those which are subject both to stresses of torsion and bending, such as the crank shafts of engines.

Shafting may be divided, according to use, into three kinds: jack shafting, line shafting and counter shafting. The *jack shaft* is belted directly from the engine, while the *line shaft* is belted from the jack shaft, the term being applied to the long lines of shafting used for transmitting the power through the shops; the term *countershaft* is applied to that shaft which receives its power from the line shaft and transmits it through tight and loose pulleys or clutches to the machine. In addition to the torsional stress due to power transmission, line shafting is also subject to bending stresses which are due, not only to the weight of the pulleys and couplings, but also to the tension of the belting as well.

As previously stated, in any computation for the strength of shafting, both the resistance to torsion and the bending must be considered. If we wish to determine the diameter of a particular shaft, we find, in our various authorities, some such formulas as these:

$$(1)\quad D = C'\sqrt[4]{\frac{HP}{N}} \text{ and } \quad (2)\quad D = C'_1\sqrt[3]{\frac{HP}{N}}$$

The above formulas have their origin in the simpler ones of

$$(3)\quad D = C\sqrt[3]{FL} \text{ and } \quad (4)\quad D = C_1\sqrt[3]{FL}$$

where D equals shaft diameter, C equals constant for the material, F equals force tending to rotate the shaft and L equals length in inches from the point of application of F to the center of the shaft.

Formula 3 is based on the fact that, under this condition, the torsional deflection of the shaft shall not exceed a predetermined angle per foot in length; and formula 4, under the condition that

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the moment FL produces a torsional stress, not more than a predetermined amount per square inch. In formulas 1 and 2 HP equals horse-power transmitted by the shaft, and N equals the number of revolutions per minute.

When shafts are subject to combined bending and torsional stresses, a value M should be used in formulas 3 and 4, where M is determined from the equation, $M = B\sqrt{B^2 + T^2}$, M being the ideal twisting moment, which would have the same effect as B and T acting together; B equals the bending and T equals the twisting moment.

The following table gives the values for C', C'_1, C and C_1 under a limited range of varying conditions. Formula 1 may be used for all solid shafts under 11 inches in diameter, while formula 2 may be used for shafts of larger size.

Material	C' for Round Shafts	C_1' for Round Shafts	C for Round Shafts	C_1 for Round Shafts
Steel.....	4.7	3.3	.297	.0828
Wrought Iron...	4.92	3.62	.31	.0909
Cast Iron.....	5.59	4.56	.353	.1145

FIG. 1951.

In general practice line shafting in shop and factory is seldom under $1\frac{3}{4}''$ in diameter, its speed, of course, being determined by the speed of the driving belt and pulleys; however, 125 to 175 revolutions per minute was the general speed for machine shops before the advent of high speed cutting tools; now double these values are often used; while, for shafts driving wood-working machinery, the speed is from 200 to 250 revolutions per minute.

1952. Shafting Supports. The distance between bearings is generally about 8 feet so that the couplings, when 16-foot shafting is used, may come close to the bearing. The distance between the bearings, however, is dependent upon the weight and the power transmitted and for shafts heavily loaded with pulleys, or transmitting large power, the bearings should be closer together.

The following table (Fig. 1952), giving maximum distances between bearings, for the various shaft diameters, is computed on the assumption that a deflection of more than $\frac{1}{100}''$ per foot of length is inadmissible.

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Steel Shafting

Shaft Diameter in Inches	Maximum Distance between Bearings in Feet
2	11.5
3	13.75
4	15.75
5	18.25
6	20
7	22.25
8	24
9	26

Fig. 1952.

1953. Bearings and Hangers. Bearings is the term applied to the pieces of mechanism in which the shaft is carried and rotates. They are sometimes called boxes. When the shaft is suspended from the ceiling, the bearing is usually suspended in a cast-iron frame called a hanger; the same frame when set on the floor becomes a floor stand, and when fastened to the wall or to a post it is termed a post-hanger. Hangers are usually provided with some method of securing alignment of their bearings with the bearings in other hangers. The most important part, however, of the hanger is the bearing, which should be lined with a good quality of bearing metal and provided with some form of self-oiling device. A self-oiling bearing usually contains a reservoir from which the oil is carried to the shaft by means of a ring or chain running on the shaft, or by suitable wicks in contact with the shaft.

1954. Pulleys, Clutches and Couplings. Commercial pulleys are manufactured either of cast iron, steel or wood and may be either split, solid, tight or loose. Split pulleys are made in halves and may be placed on the shaft at any point, while the others must be put on from the ends.

The face or periphery of all pulleys is trued and polished while the bore is machined and reamed to fit the shaft to which the pulley is fastened by means of set screws or keys.

Cast-iron pulleys should always be balanced and those of extra wide face should be provided with two sets of arms.

Steel pulleys sometimes consist of a steel rim which is riveted to a cast-iron or steel center or spider, while small ones are made

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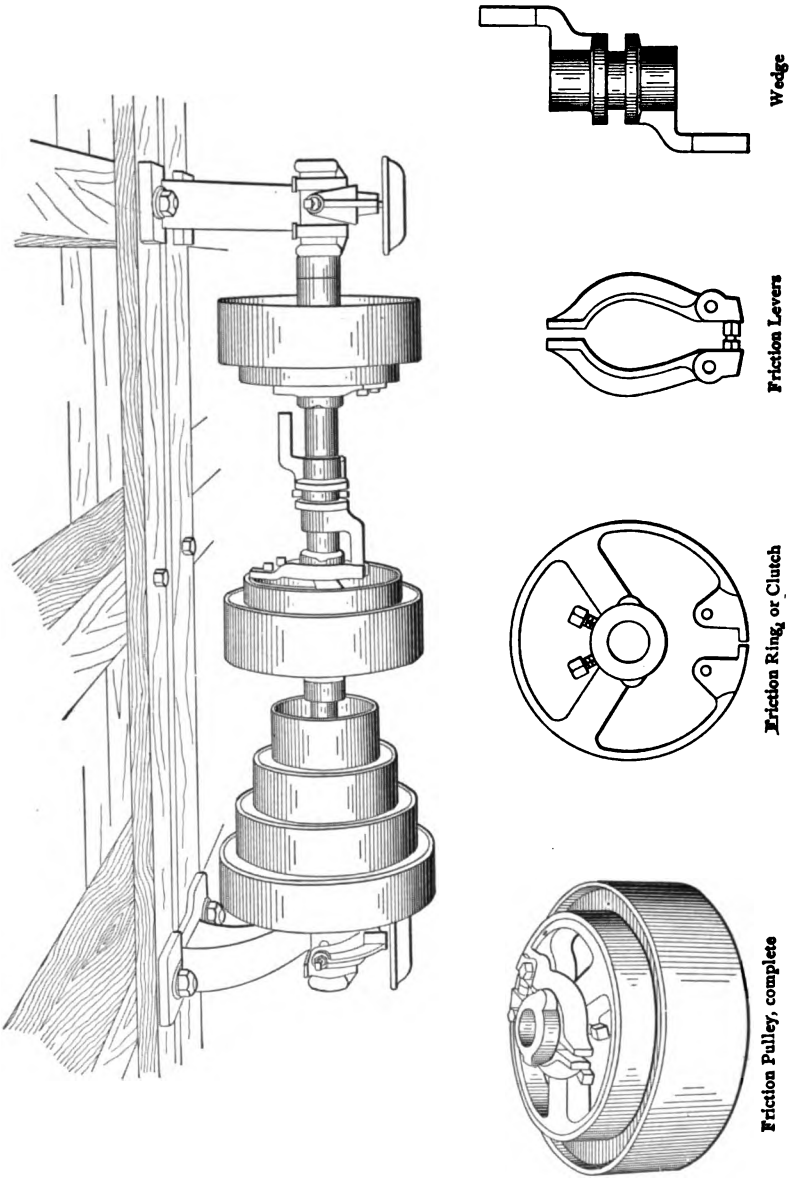

FIG. 1954a. — Reed Friction Clutch Countershaft.

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entirely of one piece of pressed steel; the advantage effected by such an arrangement being a strong, light pulley free from internal strains.

Wood pulleys are almost always made in halves and are built up of small sections of hard wood, well glued and doweled together. They are provided with bushings to fit any sized shaft,

FIG. 1954*b*. — Dodge Compression Clutch.

to which they are secured by a clamp hub. Wood pulleys are seldom used in machine shops; however, owing to their lightness they are well adapted to high-speed work.

Loose pulleys turn freely on the shaft, are used to carry a shifting belt and are made flat or straight-faced, while tight pulleys are crowned — that is, are of larger diameter at the middle of the face.

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Clutches. A clutch-pulley is often used where it is necessary to start or stop a tight pulley frequently, such as the tight pulley of a countershaft. In the clutch shown in the illustration, Fig. 1954*a*, the clutch is keyed to the shaft while the pulley runs free; when the sleeve is slipped toward the hub of the clutch, the toggle-joint closes the jaws which grip the pulley rim firmly, causing the whole to revolve with the shaft. Clutch and loose pulleys should always be provided with long bushings and suitable devices for automatic lubrication.

Couplings. The device for fastening two pieces of shafting together is termed a coupling. There are several kinds of coup-

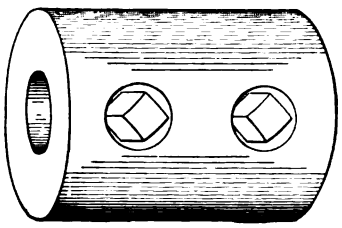

FIG. 1954*c*. — Solid Sleeve Coupling.

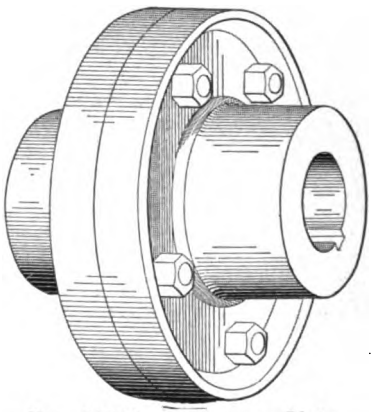

FIG. 1954*d*. — Flange or Plate Coupling.

lings on the market, the more common kinds being the flange, the compression, dental or jaw and universal couplings. Flange face-couplings are fitted to the ends of the shaft and the faces turned in place to insure accuracy and alignment. There are

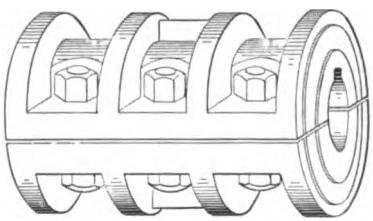

FIG. 1945*e*. — Ribbed Compression Coupling.

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many designs of compression couplings, each possessing more or less intrinsic merit. A simple kind consists of two semi circular shells — one of which carries a key-way — which are bolted together over the shaft, the shaft joint being made at the middle.

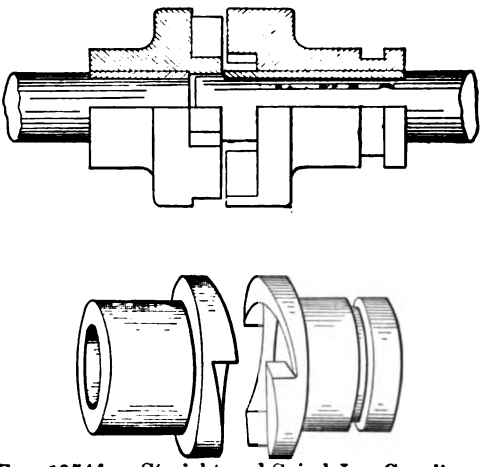

FIG. 1954*f*. — Straight and Spiral Jaw Couplings.

The key provides a positive drive, while to insure against movement a pin is inserted in the clutch and shaft at each end.

The jaw clutch is used where it is convenient to disconnect one piece of shafting from the other; this uncoupling being effected by merely sliding one side of the coupling along on the shaft.

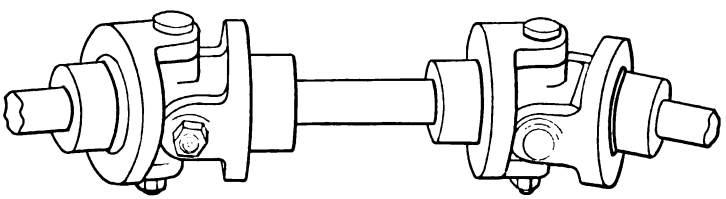

FIG. 1954*g*. — Universal Joint Coupling.

A glance at Fig. 1954*g* reveals the construction and details of the universal coupling; the forks in heavy machinery being forged and welded to the shaft. This coupling is seldom satisfactory when operated at angles exceeding 15°. However, some designs

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will act under certain conditions at an angle of 25° or greater. The objection to the universal joint is the fact that it does not transmit a uniform motion; the velocity of the driven shaft varying twice during one revolution between a velocity that is greater and one that is less than the driver.

1955. Arrangement of Shafting and Pulleys. When a horizontal open belt runs over but two pulleys, the driving should be done with the lower side of the belt, for the reason that the arc of contact is much greater in this case.

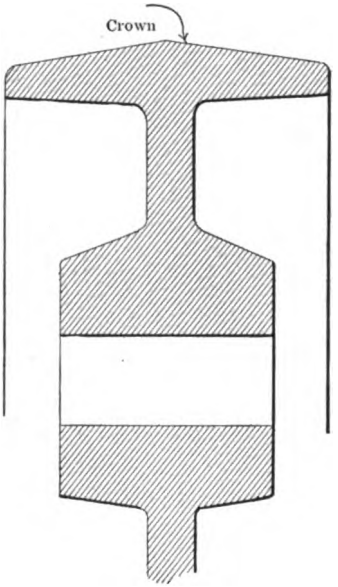

FIG. 1955*a*. — Pulley Crowning.

Idler pulleys work most satisfactorily when located on the slack side of the belt about one quarter away from the driving pulley. It is almost impossible to operate a vertical belt satisfactorily without an idler pulley, consequently the belts from countershafting should incline somewhat toward the machine. Idler or tightener pulleys operate most satisfactorily when of liberal diameter; noise, wear and injury to the belt due to short reverse bands are thus obviated.

It is common practice to have one belt run on top of the other on the driving pulley when two parallel shafts are driven from it.

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Driving pulleys are crowned because the belt tends to run on the larger diameter of the pulley.

In the Fig. 1955*b*, if for any reason the belt is forced to one

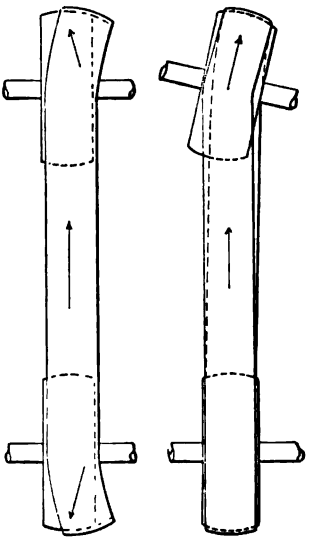

FIG. 1955*b*. FIG. 1955*c*.

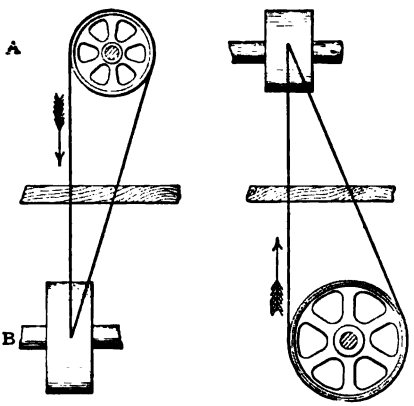

FIG. 1955*d*. — Quarter Twist Belt.

side, that edge nearest the center of the pulley is stretched and travels faster than the outer edge. This causes the belt to center itself on the pulley. A belt only runs to the high side of a pulley

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when the shafts are parallel; if the shafts are not parallel, the high side of the pulley is due to its position rather than to its

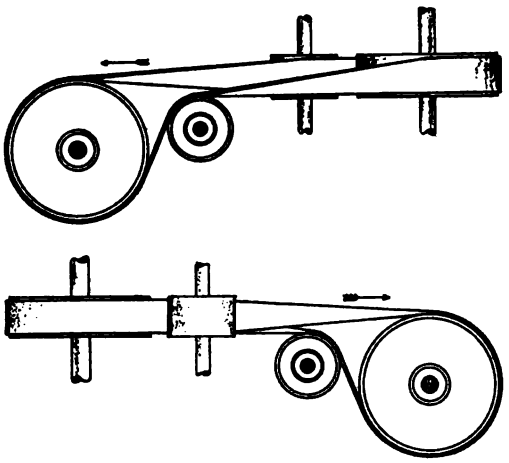

FIG. 1955*e*. — Quarter Twist Belt with Two Tighteners.

shape, and the belt runs to the low side for the reason that it passes on to the pulley in a spiral direction. All points as they

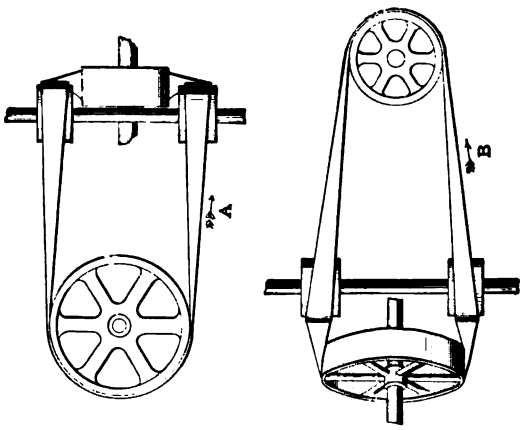

FIG. 1955*f*. — Mule Pulleys for Angle Belts.

first come in contact with the pulley being carried in the direction of the pulley's rotation as indicated in Fig. 1955*c*.

Quarter twist belts are used for connecting shafts at right

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angles with each other in different planes. Three things are necessary for a successful quarter twist drive. The pulleys must be so placed that the belt leads from the center of the face of one to the center of the face of the other; the shaft centers must be reasonably far apart and the pulleys have a face somewhat wider than those used when driving straight. The direction of rotation may not be reversed without altering the position of the pulleys. When the shafts are close together or at right angles in the same plane, a mule stand carrying two mule pulleys is used and placed as shown in the illustration. (Fig. 1955*f*.)

1956. Lining up Shafting. There are several methods of securing the accurate alignment of a line of shafting, the best way being to survey it with the transit. The line is established and marked by scratches on the heads of tacks, at each end and at intermediate distances on the floor below the hangers. A plumb line dropped from the shaft at frequent intervals is used to secure the alignment of the shaft with the line of tacks; this being effected, the shaft is made level by taking level readings on a rod placed in contact with the bottom of the shaft.

If no transit is had, the line may be established with an ordinary chalk line and the leveling effected by establishing a level on the top of nail heads driven in the floor, and then using a rod just long enough to touch the nail head on the floor and the underside of the shaft. A long straight edge and a good level — which should be reversed for every reading — are all that are needed to secure the level on the nail heads.

1957. Belts and Belting. A belt is the band, usually leather, which passes over two pulleys and transmits the motion and power from one to the other. An endless belt is one in which no joint or lacing appears, the joint being cemented in a manner similar to the rest of the belt.

Belts are usually made of oak-tanned cowhide leather, though there are belts made of rawhide, cotton and rubber. The basis of strength in rubber belting is cotton duck, the plies of which can be increased to resist any required tensile strain, the rubber coating being pressed onto this duck base. That portion of the hide best adapted for belting is what is known as the butt; the head, neck, shoulders and flanks, being uneven in texture, are not at all suited for belting. Strips the width of the belt are cut from these butts and cemented together by lap joints, to the

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required length. When one thickness of belting is used, it is known as single-ply; when two thicknesses are cemented together, it is two-ply; and when three are used, three-ply.

In some instances fast running belts, over 4000 feet per minute, are perforated; the perforations prevent air cushions from forming between the belt and pulley and allow the belt to run looser with less strain upon the bearings.

Great care should be taken in the selection of the leather used in the manufacture of the belt, as upon the quality and firmness of it depend the life and wear of the belt. Good oak bark tanned leather requires about one hundred and twenty days in the tanning process from the dry hide to the finished product. Belting butts are usually stuffed with cod oil and pure beef tallow to preserve the leather and render them suitable for the transmission of power, after which they are stretched and smoothed.

When it is necessary to run a leather belt in wet or damp places, or in the proximity of acids or dyes, some one of the many waterproofing materials on the market should be used. These generally increase the adhesive power, prevent slipping and render the belt soft and pliable. Belt dressings are supposed to perform the above functions with the exception of the waterproofing.

Belts, unless endless, are generally joined by rawhide strips termed laces, though they are sometimes laced with a special alloy wire. Hooks are also used.

1958. Belt Lacing. In laying out a splice, the try-square should always be used in order that the ends of the joint may be cut at right angles to the edge of the belt. Many an otherwise good splice is ruined by the neglect of this caution. The four styles of lacing shown by the drawings are indicative of good practice and will be discussed in the order of their arrangement.

The double-laced splice shown in No. 1, 1958*a* is often used instead of the single-laced splice similar to it. In this, as in all other splices, the lacings should be so arranged as to draw and keep the edges in line, and the lacings should not be crossed on the side of the belt that runs next the pulley. No. 1 gives a strong joint but not a lasting splice for the reason that any excessive service produces premature wear on the outer layer, which takes the bulk of the wear and tear of the lace at *A* and *B*, causing them, when worn thin, to tear out. To overcome this diffi-

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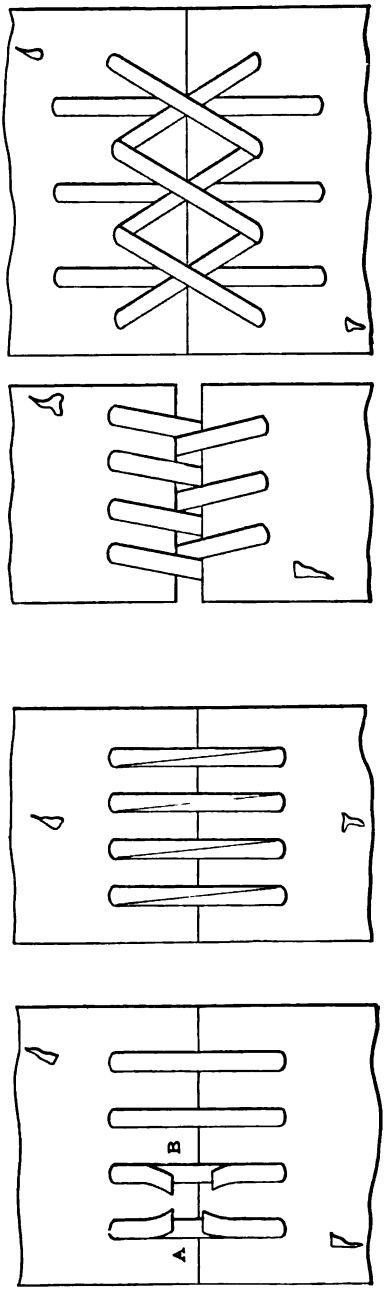

Fig. 1958a. — Belt Lacings.

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culty the style of lacing shown in No. 2, 1958*a* is oftentimes used; instead of using one end of the lace and working over and over through the holes, two ends of the lace are taken and one is drawn in over the other from the opposite side as indicated. With this arrangement, parts of the two laces come in contact with the pulleys, instead of one as before.

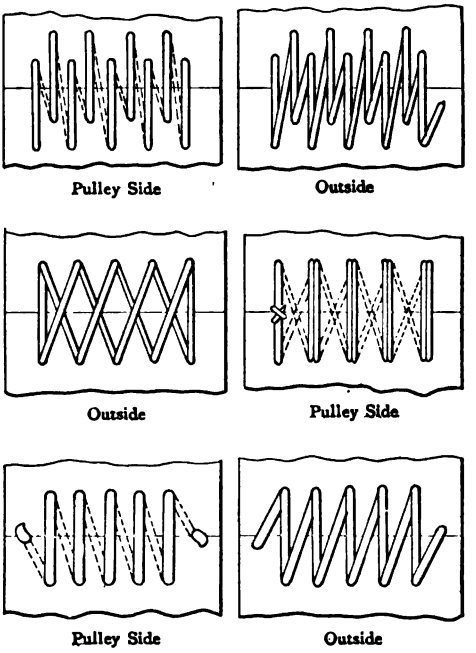

FIG. 1958*b*. — Other Belt Lacings.

No. 3 is what is termed the hinge splice and may be made double with a double row of holes or with but a single row as shown. This makes a flexible joint and one that will readily run over a small pulley. The lacing, as will be seen, is passed from the hole down between the ends of the belt, the corners of the ends of which have been previously rounded. This joint is sometimes used for its economy in belt lacing, a short piece going a considerable way.

No. 4 is an excellent lace, makes an excellent splice and is used chiefly for heavy work with belts of average width. In its

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free distribution of the stress, bringing the pull on as many different points as possible, it is better than many of the other styles in use. As in the other instances, the holes and the ends of the joint should be laid off with the try-square. Care should be taken to get each hole into the position corresponding with its mating hole on the other half of the joint. The sketch shows the outside of the lace. Commence lacing from the center and proceed as indicated.

Another series of belt lacings is shown in Fig. 1958*b*.

1959. Horse-power Transmitted by Leather Belting.

TABLE GIVING THE HORSE-POWER TRANSMITTED BY LEATHER BELTS ONE INCH WIDE, CONSIDERING THE EFFECTS OF CENTRIFUGAL FORCE, SO THAT THE TENSION ON BELT IS CONSTANT AT ALL SPEEDS

Speed in Feet per Minute	Single $\frac{1}{16}$" thick	Double $\frac{1}{8}$" thick	Triple $\frac{3}{16}$" thick	Four-ply $\frac{1}{4}$" thick
100	.14	.24	.33	.44
200	.27	.48	.67	.88
300	.41	.73	1.00	1.32
400	.54	.96	1.33	1.75
500	.68	1.21	1.66	2.19
600	.81	1.44	1.99	2.62
700	.95	1.68	2.31	3.05
800	1.08	1.93	2.64	3.48
900	1.21	2.15	2.96	3.90
1000	1.34	2.38	3.28	4.32
1100	1.47	2.61	3.59	4.73
1200	1.60	2.85	3.90	5.14
1300	1.73	3.07	4.21	5.55
1400	1.86	3.30	4.51	5.94
1500	1.98	3.53	4.81	6.34
1600	2.10	3.73	5.10	6.72
1700	2.23	3.94	5.39	7.10
1800	2.34	4.15	5.67	7.47
1900	2.46	4.35	5.94	7.83
2000	2.58	4.56	6.21	8.18
2200	2.80	4.94	6.73	8.85
2400	3.01	5.30	7.21	9.51
2600	3.21	5.65	7.67	10.09
2800	3.40	5.97	8.09	10.64
3000	3.58	6.25	8.47	11.14

Table continued on page 452.

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Speed in Feet per Minute	Single $\frac{3}{16}$" thick	Double $\frac{3}{8}$" thick	Triple $\frac{9}{16}$" thich	Four ply $\frac{3}{4}$" thick
3200	3.74	6.52	8.80	11.58
3400	3.89	6.74	9.10	11.96
3600	4.03	6.95	9.35	12.28
3800	4.14	7.12	9.55	12.57
4000	4.24	7.26	9.70	12.73
4200	4.33	7.36	9.79	12.84
4400	4.39	7.42	9.83	12.88
4600	4.43	7.44	9.80	12.84
4800	4.45	7.42	9.72	12.71
5000	4.45	7.37	9.56	12.50
5200	4.43	7.26	9.34	12.20
5400	4.38	7.10	9.05	11.80
5600	4.31	6.92	8.69	11.30
5800	4.21	6.65	8.25	10.70
6000	4.09	6.35	7.73	10.00
6200	3.94	6.01	7.13	9.19
6400	3.76	5.58	6.44	8.26
6600	3.56	5.11	5.67	7.22
6800	3.32	4.57	4.80	6.06
7000	3.05	3.98	3.84	4.77
7200	2.75	3.31	2.79	3.36
7400	2.42	2.60	1.64	1.82
7600	2.05	1.82	0.39	0.14
7800	1.65	0.95		
8000	1.21			
8200	0.74			
8400	0.23			

$$HP = \frac{(T - 0.012\, t\, V^2)\, V}{500}$$

t = thickness of belt in inches.
T = working tension of belt.
$T - 0.012\, t\, V^2$ = effective tension of belt.
T = 45 *lbs*, 80 *lbs*., 110 *lbs*., 145 *lbs*.
V = velocity.

FIG. 1959.

For belts more than one inch wide, multiply the width by the value in the table.

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CHAPTER XX

MOTOR DRIVES AND MOTOR-DRIVEN MACHINE TOOLS

2011. Advantages of Motor Drives. The chief advantages of a system of individual motor drives for machine tools, etc., aside from the great economy of such a system, are the absence of overhead shafting; giving better light and crane service; its convenience for detached buildings; the independent location of machines; the speed control and easy manipulation and as an inevitable result of these conditions its introduction leads to new methods, which not only secure a greater output but also an increase of excellence in the product. Chas. F. Scott says: "The introduction of the motor into the machine shop has resulted in new methods of applying power and controlling it, which have not only increased the output of the tool, but have reacted upon its design so that new methods have been worked out leading to radical advances. It may be noted that in the rapid and radical change which has taken place in machine shop practice, high-speed tool steels and motor drives are the important factors, though the principal features which enable the motor to play so important a role in this change are mechanical rather than electrical, viz., speed regulation and control."

The accompanying chart (Fig. 2011, page 454) illustrating the principal advantages and various methods that may be adopted for driving machine tools was made in 1903 by Dodge and Day.

2012. Relative Costs of Equipment. As the total cost of power in a large factory is a very small percentage of the entire cost of production — from 2% to 5% — motor drives gained but little popularity with manufacturers until it was demonstrated that, besides reducing the cost of power, with them it was possible to reduce the cost of labor, to increase the output, to improve the product, to reduce power demands and to use greater power more effectively.

Regarding the first cost of installation, G. M. Campbell, in an

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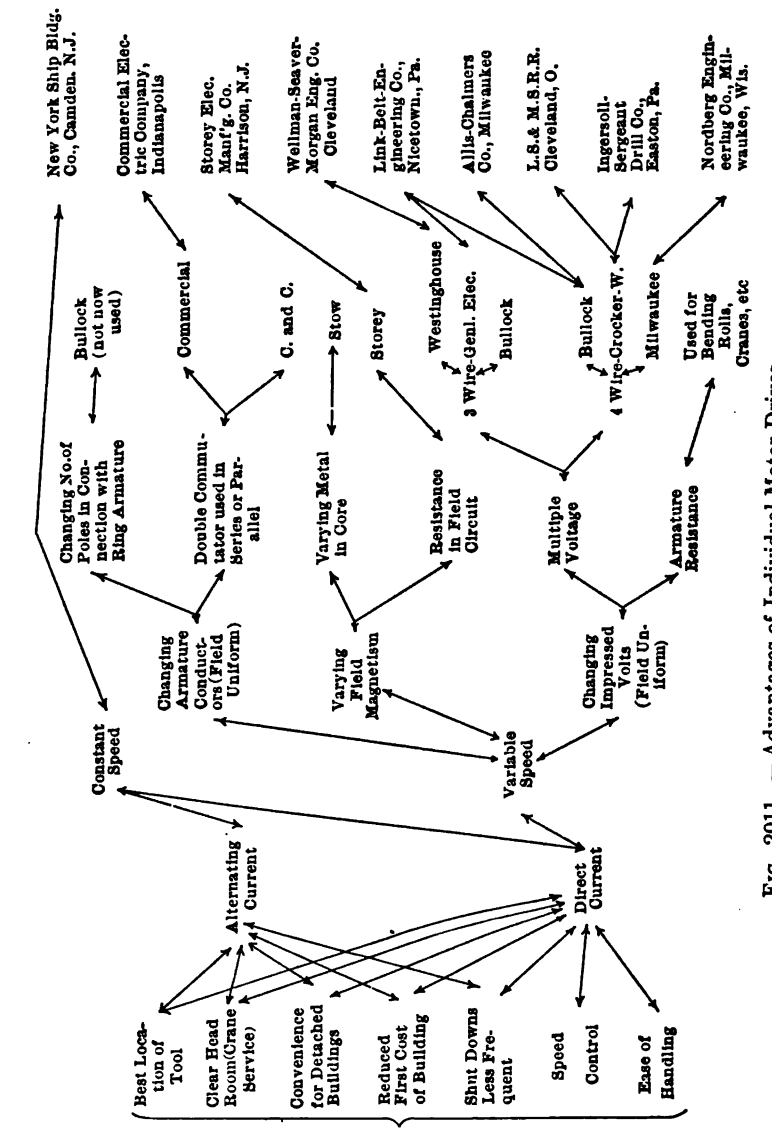

FIG. 2011. — Advantages of Individual Motor Drives.

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article on "Machine Shop Practice," read before the Engineering Society of Western Pennsylvania, makes the following remarks: "It may be readily proved that for any tool in which variation in speed is required, large or small, that the installation of an individual motor drive with 10% speed increments will be an economical investment. The time is coming when practically every metal-working tool where speed changes or changes in material are required, will be, in an up-to-date machine shop, equipped with its own individual motor and at practically the price of the present tools." Until recently it was generally considered that the individual motor drive was more expensive than the group drive system. However, a careful inspection of the report by the Committee of the Master Mechanics' Association regarding the shops of the Lake Shore Railroad shows that just the reverse is true, as will be seen from the following extract:

LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COLLINGWOOD SHOPS
ESTIMATED COST FOR INDIVIDUAL DRIVE

103 Motors	$12,340.00
Wiring 103 Motors @ $18.30	1,884.00
Wiring 242½ H. P. @ 5.40	1,164.00
	$15,388.00

COST FOR GROUP DRIVING

11 Group Motors	$4,550.00
Wiring 11 Motors @ $18.30	201.30
Wiring 202 ½ H. P. @ 4.80	972.00
Countershaft, Line, Belt, Pulleys, etc.	6,667.00
Belting	3,881.00
	$16,271.30

The result is even more favorable, says the report, to the individual drive than appears in the estimate, for the roof construction of the shop would have had to be appreciably heavier to support the line and countershafting. Nor does any item in the report cover the cost of belt shifters and the erection of the belting for the group driving which, for 103 tools, is quite an expense.

2013. Economy of Motor Drives. As practical evidence of the advantage and economy of electric driving, the Westinghouse Electric Co. cite a case where thirty steam engines of 1375 total horse-power were supplanted by fifty-seven motors of 1065 total

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horse-power for machine shop driving and where the average daily saving in steam was 41.6%; and of combustible, 31.2%. In other cases, according to the *American Machinist*, electric driving has reduced by 50% the cost for engineer, coal and water; the fuel account, 20%, and the cost of power, 44%. The gross saving was 30% with direct-connected motors and 22% with belted or geared motors.

Concerning the economy in the operation of motor drives, the results that obtained at the Pittsburg and Lake Erie Shops during the year 1904 are given as being typical. For this year the average horse-power taken by all machine-tool motors was about 200 during the working hours. The average power consumption at present, 1906, is about 300 or 30% of the horse-power rating of the 83 motors, the average horse-power of each being 12.05. Only 17.3% of the power-house output was used by the machine tools, it being 38.71% of the total electric power; the lighting consumed 24.9% while the heating and ventilating motors took 23.78%.

A tabulated horse-power consumption for each type of work is as follows:

Variable Speed Tools	39.71%
Constant " "	26.80%
Blast Fans	28.44%
Cranes	5.05%
Total,	100.00%

The total cost of power for the machine tools and cranes, exclusive of maintenance, was $2,662.66. The power-house capacity is 600 kilowatts and with an overload rating of 25% it would be 750 kilowatts. The motor rating for the 83 motors above mentioned was 1000 horse-power.

It will, no doubt, be surprising to note that the power losses which obtain when all machines are running light may reach or even exceed the average power consumption throughout the working days. To illustrate this point, the following diagram (Fig. 2013) is taken from an excellent article by Mr. Campbell on "Power Required by Machine Tools." This paper was read, February, 1906, before the Engineers' Society of Western Pennsylvania. The good results obtained in the Pittsburg and Lake Erie Shops may be indicated from the fact that where formerly

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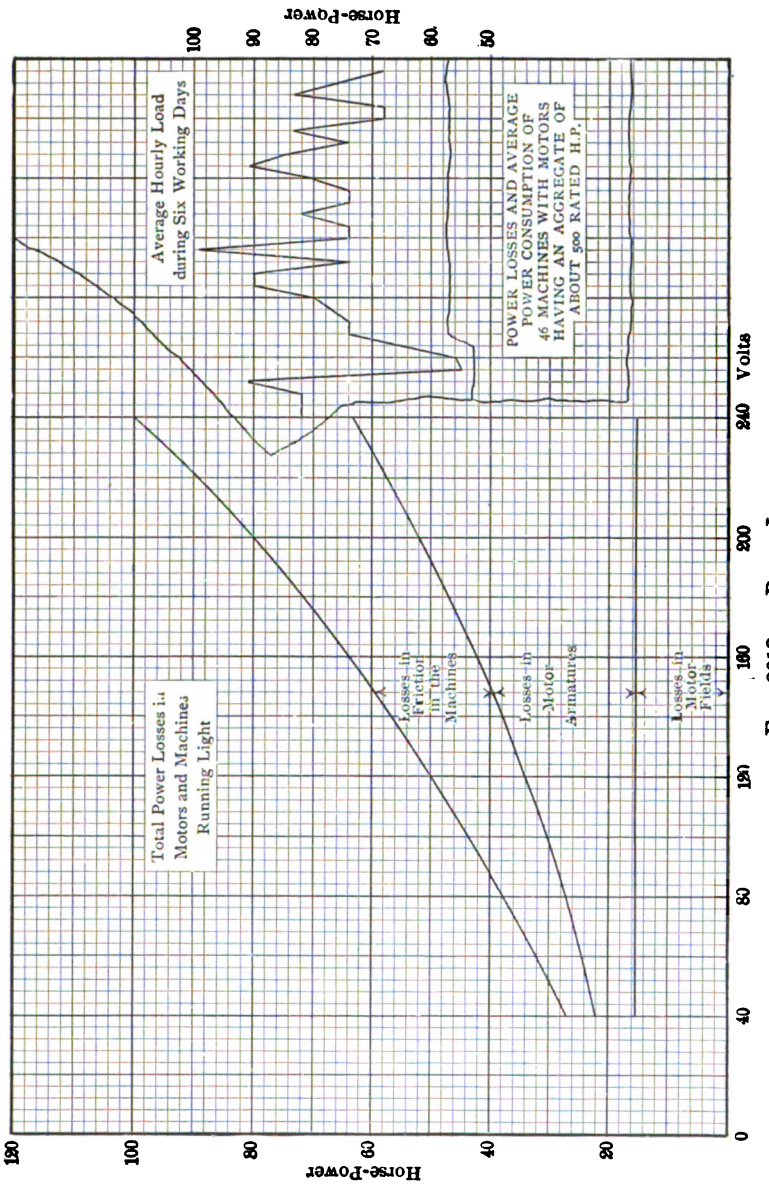

Fig. 2013. — Power Losses.

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it was possible to overhaul five to seven locomotives each month, now fourteen to twenty are overhauled and the new shops are considered such an excellent investment that it is estimated that they will have paid for themselves, including first cost and interest, in ten years or less.

Motors for Shop and Machine Tool Driving

2021. Constant-speed Motors. Under this heading are classed motors whose average variation from no load to full load is not over 5%. Their general characteristics, as may be seen from the plotting of heavy lines in the diagram — "Typical Curves for Shunt and Compound Motors" (Fig. 2021) — are as follows: In all but the synchronous motor — which gives absolutely a constant speed if the cycles of the circuit upon which it operates remain constant — the speed is approximately constant, falling slightly with the load. The torque and brake horse-power are closely proportional to the armature current, while the motor automatically adjusts itself to give constant speed as the different loads come on it.

Mr. Day remarks that the constant-speed motor, particularly of the alternating type, is so simple in character that we naturally turn to it as the possible solution of the problem of direct-connected machine drives. He states that it lacks two great essentials, viz., ease of handling and speed regulation, and that all attempts to supply these shortcomings by mechanical means have, so far, proved unsatisfactory. His statement that the induction motor is merely a source of power, just as the line shaft, carries with it the inference that it is inflexible as to speed regulation; however, W. I. Schlichter, in a paper before the A. S. M. E., June, 1903, presents several successful methods of controlling and varying the speed of alternating-current motors.

The different types of motors are classified by W. Edgar Reed as follows:

- Constant Speed Variable Torque
  - Continuous Current
    - Shunt Wound
  - Alternating Current
    - Induction
      - Single-phase
      - Poly-phase
        - Wound Rotor
        - Short-circuited Rotor
    - Synchronous
      - Single-phase
      - Poly-phase

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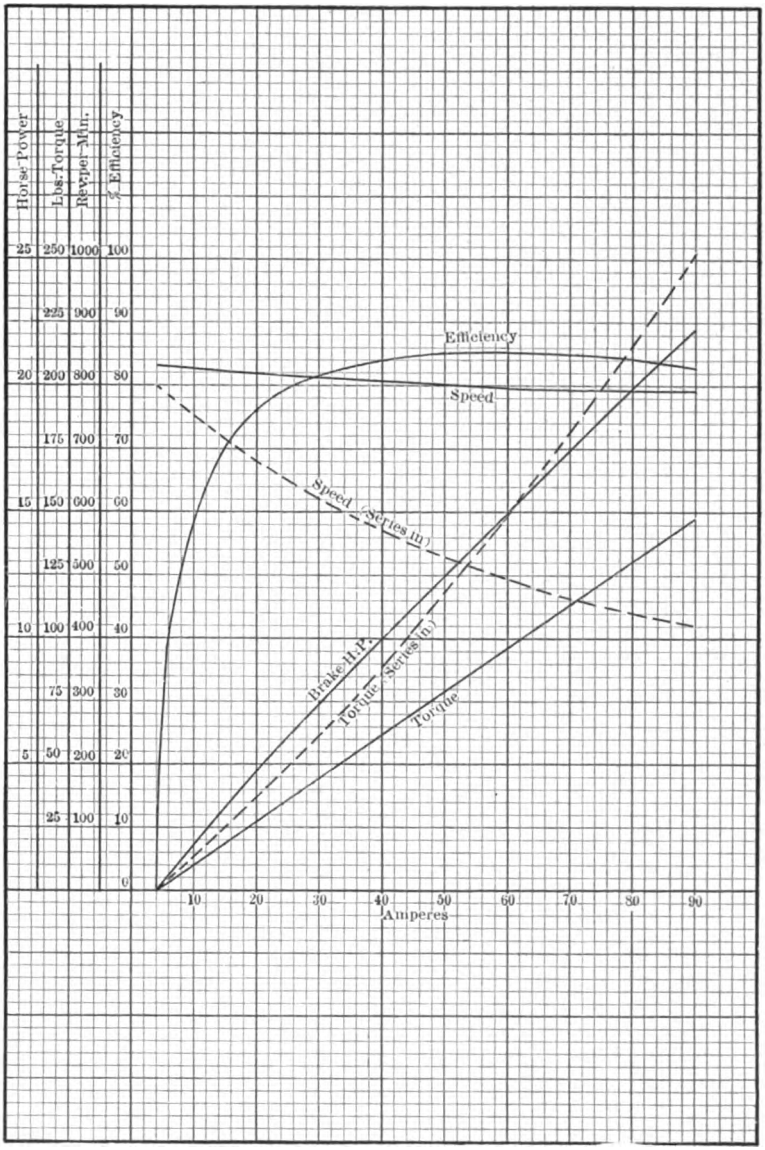

FIG. 2021. — Typical Curves for Shunt and Compound Motors.

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Their characteristics are classified in the following table:

Shunt Wound		Characteristics noted on diagram; normal speed may be varied by changes in field strength.
Induction	Single-phase	Built in small sizes and for operation on lighting circuits. Small starting torque, large line current to start — must be brought up to nearly full speed before load is thrown on.
	Poly-phase	Adapted for polyphase lighting circuits. Starting current for developing full load; torque only slightly in excess of full load current. Running characteristics similar to those of shunt-wound motor except that it has but one definite speed.
Synchronous		Absolutely constant speed, no starting torque; not self-starting with load. Must have continuous current available for field excitation. Used principally in large sizes.

2022. Variable or Adjustable Speed Motors. In general, this class of motors is designed to give automatically a wide range of speeds for the different torques and outputs required of it. They have no definite horse-power rating but are generally rated at the horse-power they develop for one hour within a stated rise in temperature; the rises most often selected being 40°, 60° or 75° Centigrade. The selection of a suitable motor of this type should depend largely upon the maximum torque required of it and this should be developed without undue sparking or heating.

Plotted on the same diagram (Fig. 2022*a*) for comparison are the general characteristics of this class of motors; the one on the left gives characteristic data either for the series-wound continuous or the single-phase, series-wound alternating-current motor, while the one on the right shows the same data for the polyphase induction motor.

The different types are thus divided by W. Edgar Reed in the table:

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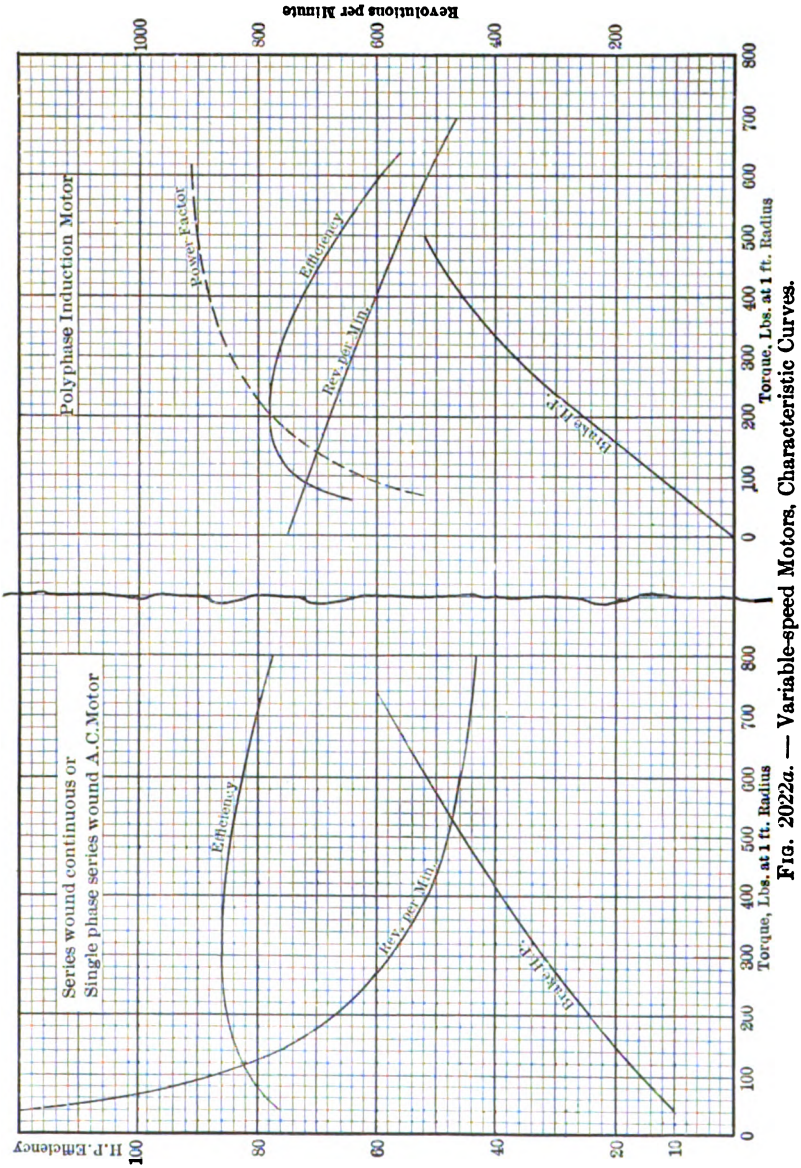

Fig. 2022a. — Variable-speed Motors, Characteristic Curves.

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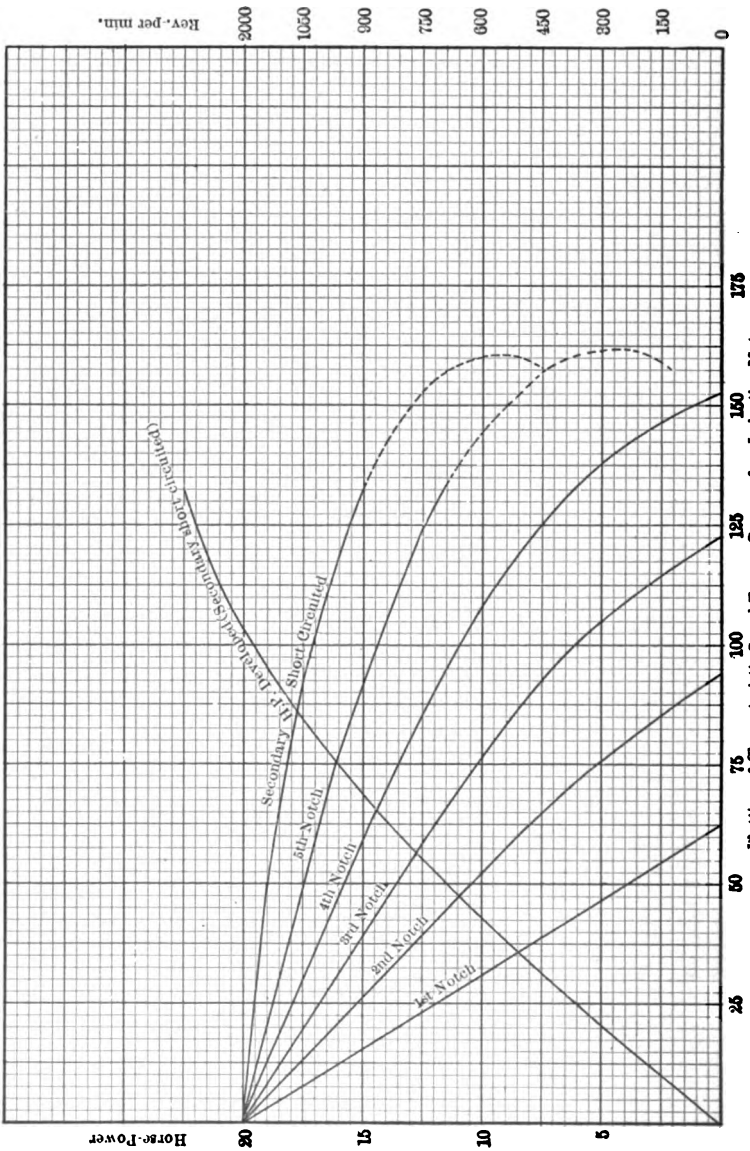

Plotting of Characteristic Speed Torque Curves of an Induction Motor

FIG. 2022*b*. — Speed-Torque Curves.

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Variable Speed Variable Torque
- Continuous Current
  - Series Wound
- Alternating Current
  - Single-phase, Series Commutator
  - Poly-phase Induction[1]
    - Wound Rotor
    - Short-circuited Rotor

A classification of the characteristics of the variable or adjustable speed motors are as follows:

Series Wound	40% to 75% speed increase with half load. Speed varies inversely as load running at such a speed with no load that they are liable to burst. Torque and brake-horsepower increase as the current increases.
Single-phase Series Commutator	Some of the general characteristics of direct-current motors. Single-phase series motors excellent for railway and similar classes of service.
Poly-phase Induction	10% to 15% speed increase with half-load. Speed varies inversely as the load. Any torque at any speed over a wide range. Torque maximum at starting, decreasing uniformly as the speed increases except at low speeds. See plotting for torque speed curves, Fig. 2022b.

2023. Compound Motors. Because the compound motor has two independent field windings, one a shunt and the other a series, the shunt being connected in a similar manner to the field winding of the simple shunt motor and the series winding carrying the armature current, it possesses some of the characteristics of both the constant and variable speed motors. It has a greater maximum starting torque than the constant-speed and a lesser than that of the variable-speed motor; and, while the current for a given starting torque is less than that for the constant-speed motor, it is greater than that for the variable-speed motor.

The characteristic curves in dotted lines were plotted, for comparison, on the diagram "Typical Curves for Shunt and

[1]Given in both classifications. "A slight difference in design of the short-circuited rotor motor will change a constant-speed motor requiring fairly large current from the line at starting, to a variable-speed motor requiring much less current from the line for the same starting torque." The wound rotor motor may also be easily changed from one class to the other.

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Compound Motors" in Sec. 2021, Fig. 2021. These curves were taken from tests upon the same motor, first with shunt and series windings both operating, and second with only the shunt winding in operation. Compound motors have a fixed no-load speed, the speed varying inversely as the load, *i.e.*, high speed at a light load.

The different kinds of motors having characteristics of the compound type are thus tabulated by Mr. Reed, who states that "the so-called compound motor is generally of the continuous-current type but that polyphase induction motors of the short-circuited or wound rotor types are made and these have nearly the same operating characteristics."

- Compound Motors
  - Continuous Current
    - Compound Wound
  - Alternating Current
    - Induction
      - Poly-phase
        - Short-circuited Rotor
        - Wound Rotor

This motor is especially valuable for driving reciprocating machinery, planers, shapers, printing presses, etc., because it holds in check the surge of current from the line at the instant of reversal, at the time when the maximum torque is required.

2024. References to Other Data. For other information regarding electric motors the student is referred to that portion of Chapter 19 on "Power Transmission" which deals with electric transmission, and especially to Sections 1915, 1916, 1917 and 1918. Should a more exhaustive study of motors and motor driving be desired, much valuable information may be had from the articles on "Feed Characteristics and the Control of Electric Motors," by Chas. F. Scott, which appeared in the *Engineering Magazine* of April and May, 1906; a paper by W. Edgar Reed on "Electric Motors and Their Application," published in Vol. 21, 1905, of the Proceedings of the Engineers' Society of Western Pennsylvania; and to two papers by G. M. Campbell which appeared in the Proceedings of the same society, one in November, 1905, and the other in February, 1906; one dealing with "Machine Shop Practice," and the other with "Power Required for Machine Tools"; and again, to a paper by Robert T. Lozier, read before the New York Electrical Society and distributed by the Bullock

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Electric Mfg. Co., on the "Electrical Operation of Modern Machine Tools and Machinery."

Working Applications of the Various Motors

2031. On the Choice of a Motor. In general, it may be stated that more than one type of motor may be used to perform a given kind of work, and conditions of electrical distribution alone may determine the selection. It is very important, however, to know all the conditions required of the service as special conditions ofttimes exert a preponderating influence in the choice of a motor.

2032. Constant-speed Service. The purpose of the following list is to give a few general applications of drives requiring the use of constant-speed motors:

Wood-working Machinery, Lathes, Circular and Band Saws, etc.

Fans, Blowers, Air Compressors.

Such Machine Tools as have Rotary Motion, Lathes, Drills, Milling Machines, Boring Mills, etc.

High and Slow Speed Centrifugal and Reciprocating Pumps.

Shoe-making Machinery.

Laundry Machinery.

Hydraulic Elevators.

Line Shafting which requires a fairly constant speed with few stops.

2033. Variable or Adjustable Speed Service. Because of the tendency in the series motor to run away at low or no loads, and because of temperature, sparking and other conditions in other types of this class, variable-speed motors find their general application in cases where the motors are always under control of the operator. In this class of service are found:

Street Railway Motors.

Locomotives.

Cranes, Hoists, Elevators, etc.

Used for service requiring frequent stops and high-speed averages.

2034. Drives and Tools Requiring Compound Service. As has been previously stated, this motor finds its largest application in driving reciprocating machinery where a full load is thrown suddenly and intermittently on the machine. Under this class of service are placed:

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Machine Tools having Reciprocating Motion.
Planers, Shapers, Slotters and Presses.
Punches, Shears and Presses.
Hoists, Elevators and Cranes.
Bending and Straightening Rolls.
Printing Presses.
Crushers, etc.
Roller Beds.

Speed Regulation

2041. Speed Ranges. As is evident, to even the novice, machine-tool work requires speed variation for economic production. How much or through what range and what proportion is to be taken by the motor and what part can be had in the tool itself are the problems. A motor can be made to operate at any speed between 0 and the maximum, but it becomes abnormally large for great ranges, as the speed is a direct function of the power. Electric manufacturers say that the practical range is 6 or 7 to 1, though this may be increased to 10 to 1 without difficulty. Generally speaking, from the shop man's standpoint, it seems best with the present motors and tools not to exceed 4 to 1 in the motor, obtaining the rest of the variation by runs of gears, though just what speed range to give the motor cannot be stated for all conditions.

With a lathe having a spindle-speed variation say of 26 to 1, the variation could be obtained with four runs of gears and a speed variation in the motor of 3 to 1. With the gears, "run 2" would give three times 1; "run 3," three times 2; and "run 4," three times 3, and as this is a range of 300%, the motor is given 3 to 1 and operates as follows: starting with the lathe running with "run 1" and the motor at initial speed, the speed may be brought up gradually by any increment until it is three times the initial speed; "run 1" is now dropped out, "run 2" thrown in and the motor brought back to its initial speed, giving the next speed to the spindle above that with "run 1" and so on through the entire range.

Speed increments of only 5% or less may be necessary, but for the regular run of work increments of 10% will be found suitable and with this increment the number of controller points obtained by the formula given by G. M. Campbell will be:

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Speed Range of Motor = 1.1^{n-2}. The off-point being counted as one (n being the total number)

Speed Range		Controller Points
3	=	14
4	=	17
5	=	19
6	=	21

This gives the forward points and to it must be added the required number of backward points, usually one third or half the number of forward ones.

2042. Speed Control. As a rule, the speed of any motor is dependent upon two factors, viz., the field strength of the motor and the electro-motive force or voltage applied to the armature; this being the case, a constant speed results if the voltage and the field strength are a constant, though the load may vary. Again, a constant speed results if a decrease in either element is accompanied by a corresponding increase in the other, and furthermore it is seen that a variable speed would result from a variation of either element alone or an unequal variation in both.

There are several methods of speed control, usually variations of two general types: (1) Speed control by field strength and (2) speed control by armature voltage. In Bulletin No. 1007, the Bullock Electric Mfg. Co. give the three methods herewith, making the objections noted after each. They only indicate practice in a general way and nothing is said here in reference to the Bullock Electric Mfg. Co's patented system of multiple-voltage control which is a very successful and efficient one.

(1) Speed control by field strength: Changing the total amount of magnetism — the armature conductors and impressed volts remaining a constant. With this method the two governing factors are opposed to each other; *i.e.*, increasing the number of conductors on the armature to avoid trouble at slow speeds gives just the opposite effect at high speeds. A speed range of only 2 to 1 may be obtained and the machine sizes are abnormal for the horse-power output; a 2 to 1 range necessitating a motor four times the required size.

(2) Speed control by armature voltage: Changing the impressed electro-motive force at the motor terminals by connecting the armature across the lines carrying different voltages, these voltages being maintained a constant direct from the generator.

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This system is on a par with using resistance in the armature circuit to vary the electro-motive force as regards the size of the motor.

(3) Changing the number of poles and at the same time the armature connections to correspond. With this method an eight-pole machine would give, approximately, $\frac{1}{4}$, $\frac{1}{2}$ and full speed; a sixteen-pole machine, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ and full speed. There are many serious defects to this system such as loss of torque, when the poles are reversed, stopping, etc.

After discussing at length the different methods, Pres. Chas. F. Scott of A. I. E. E. makes the following statement: "A comparison of the foregoing methods of speed control shows several points in favor of control by variation of the strength of the shunt field, when adjustable speeds are desired, which shall be constant, independent of load variations. The motor and control devices are simple; the supply circuit is of the simplest kind without special generators or additional wires. The current is always minimum, as no low voltages are used which would require a greater current for a given power."

In spite of this fact, the multiple-voltage system has met with great success in a number of large machine shops.

2043. Speed Control Relations. The following definite relations obtain between the voltage, current, speed and torque, and are given here in order that a better understanding may be had regarding speed control.

(1) Horse-power is proportional to speed $\times$ torque.

(2) Power is proportional to E.M.F. $\times$ current.
If E.M.F. be constant the speed is a constant.

(3) Therefore torque, H.P. and current vary together.

(4) If the load be doubled, both the torque and current are doubled; under these conditions it follows that the torque and current are proportional.

(5) If the E.M.F. applied to the armature be varied, the speed changes in like proportion.

(6) With a definite, constant field strength the speed is proportional to the applied E.M.F.; and the torque is proportional to the current.

2044. Systems and Wiring. The different systems of wiring are the single-voltage or 2-wire, the two equal voltage or 3-wire and the multiple-voltage or 4-wire. In all the systems the size

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of motor required is about the same. A 2-wire installation already in service can incorporate without any trouble any number of variable-speed, single-voltage motors.

The 3-wire system is a cross between the multiple voltage and 2-wire with part of the good and part of the bad points of each.

In brief, the multiple voltage system, which is a type of speed control by armature voltage, consists of several sources of current supplied at different voltages, each differing by a fixed ratio. We may have a 3-wire system which has 220 volts on two of its wires and 110 volts between each of these and the middle wire, which gives us two speeds at a ratio of two to one: then again, we may have a 3-wire system with unequal voltages; for example, 80, 160 and 240 volts, dividing the maximum voltage into thirds instead of halves as in the former instance. Or we may have a 4-wire system between which the following voltages are maintained: 60, 80 and 110 volts respectively. The different voltages obtained with this arrangement are 60, 80, 110, 140, 190 and 250. Such an arrangement with a small range of shunt-field regulation could be given a speed range of about 6½ to 1.

Speaking of the multiple-voltage system Mr. Scott says: "The principal advantages in the use of the multiple-voltage system involving a considerable number of voltages are that less range of speed is necessary in the field control." And as before stated he goes on to recommend the control by the variation in strength of the shunt field. For reciprocating machine tools, the multiple-voltage system is undoubtedly advantageous. Another strong point in favor of this system is that standard motors are used.

Horse-power Requirements

2051. Motor Ratings. The plottings on the diagram herewith (Fig. 2051) are taken from Mr. Campbell's paper and indicate how little reliance may be placed upon the manufacturer's rating of a motor. A "5 H.P. Motor" means very little unless we know the conditions under which it operates or on what particular basis the rating is made.

From the diagram it may be seen that a 5 horse-power motor may weigh (and cost somewhere in proportion) from 360 to 1600 pounds. And again that one might pay for and receive a 30 horse-power motor when the rating called for but a 5 horse-power motor.

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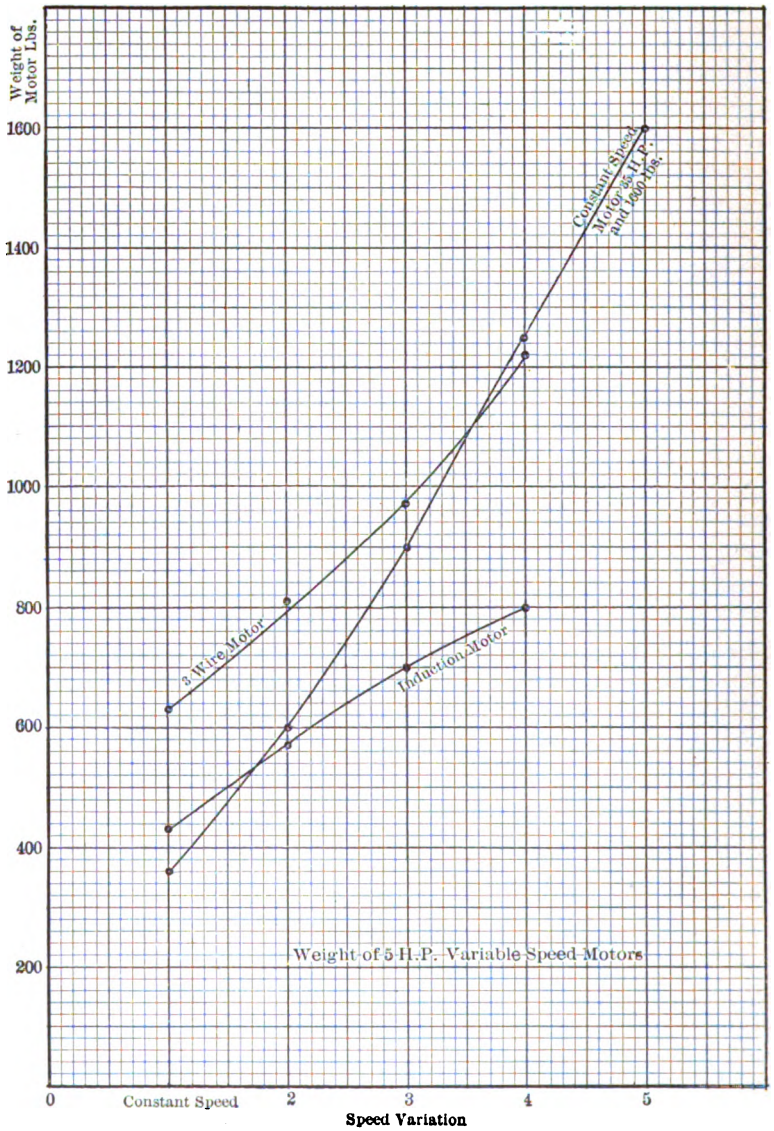

FIG. 2051. — Weights of Variable-speed Motors.

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2052. Power Requirements of Reciprocating Tools. The selection of a motor for reciprocating machine tools such as planers, shapers, punches and shears is almost independent of the cut taken and depends largely upon the machine itself. The following data are taken from a test made on a 60″ planer. During the cutting stroke, the horse-power reading was 3.9; reversing to return stroke, the power ran up to 19. On the return stroke the reading, was 6.3, while in reversing to the cutting stroke a reading of 27 horse-power was had. The readings were taken with the machine running light, the speed of the cutting stroke being 25 and of the reverse stroke 60. This machine was driven by a 20 horse-power motor. Readings were taken on the power required for punches, the horse-power jumping from .6 when running light, to 24 horse-power while punching $1\frac{3}{8}$″ holes in a $\frac{7}{8}$″ plate. It is evident that this class of work requires some sort of a balancing device to offset such fluctuations. To this end, motors driving this class of service should be equipped with a fly-wheel of large diameter and heavy rim, to assist the motors at the instant of reversal. The fly-wheel may be placed somewhere in the driving mechanism, but it is vastly to be preferred mounted on the motor shaft.

2053. Campbell's Formula. In his investigations, Mr. Campbell discovered that, other conditions being the same, the power taken by the machine, after allowance is made for friction losses, will vary approximately as the speed and cut and therefore as the weight of metal removed; consequently, in fitting motors to tools, due allowance must be made for high speeds and maximum cuts, bearing in mind the coming universal use of high-speed tool steels and increase in rigidity of machines. Mr. Campbell's formula for the power absorbed in cutting is thus stated:

$H.P. = K\,W$, where $H.P.$ = Horse-power; K = a constant depending on the kind and grade of material; and W = Weight of Metal, pounds removed per minute.

Values of K may be taken as follows:

K = 2.5 for hard steel.
= 2.0 for wrought iron.
= 1.8 for soft steel.
= 1.4 for cast iron.

In comparing the results obtained by this formula with the

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actual horse-power noted in a large number of instances and on a wide range of work, some wide variations were noted; but the agreement in general was sufficiently close to show that the formula is a reasonable one for arriving at the approximate horse-power required for doing the actual work.

2054. Horse-power Required to Remove Chips of Given Area. The charts, four in number, give the horse-power required to remove chips of a known area (depth of cut times feed) at the ordinary rates of speed. The horse-power obtained will be found ample and the speed range and area of the chip as plotted are sufficient to give data for even the heaviest cuts with high-speed steels. The method of using these diagrams, Figs. 2054*a*, *b*, *c* and *d*, is: It is desired to know what horse-power is required to remove, from soft steel, a chip $\frac{3}{16}'' \times \frac{1}{8}''$ ($\frac{3}{16}''$ deep $\times$ $\frac{1}{8}''$ feed) at a speed of 40 feet per minute. On the chart for soft steel find the curve marked 40 feet, follow this down until it intersects the $\frac{3}{16}''$ abscissa. The reading directly below, 8.54, gives the horse-power required to remove a chip $\frac{3}{16}''$ square. $\frac{2}{3}$ of this value, of course, gives the horse-power required to remove the chip $\frac{3}{16}''$ x $\frac{1}{8}''$ or 5.7 horse-power. These horse-powers will be found ample and, though calculated by Campbell's formula, are about the same as when calculated by Mr. Pomeroy's formula which appeared in the General Electric Review, 1908.

$$\text{Horse-power} = F \times D \times f.p.m. \times 12 \times N \times C.$$

where F = feed in inches.
D = depth of cut.
$f.p.m.$ = feet per minute.
N = number of tools cutting.
C = a constant depending upon the material.

The horse-powers in the table may be obtained by giving C the following values: Hard steel, $C = .71$; wrought iron, $C = .51$; soft steel, $C = .51$; cast iron, $C = .37$.

The tables (Figs. 2054*aa*, *bb*, *cc* and *dd*) accompanying the charts, not only give the horse-power required, but also the weight of metal removed per minute for the given cut and speed.

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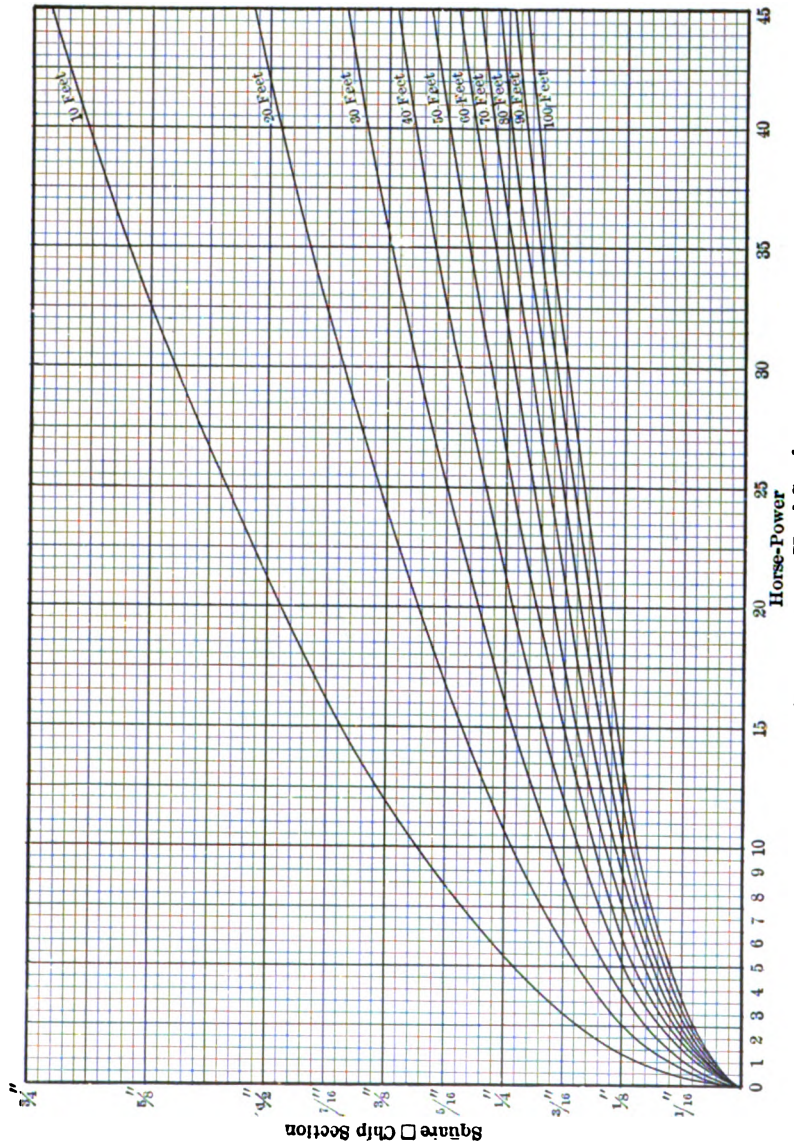

Fig. 2054a. — Hard Steel.

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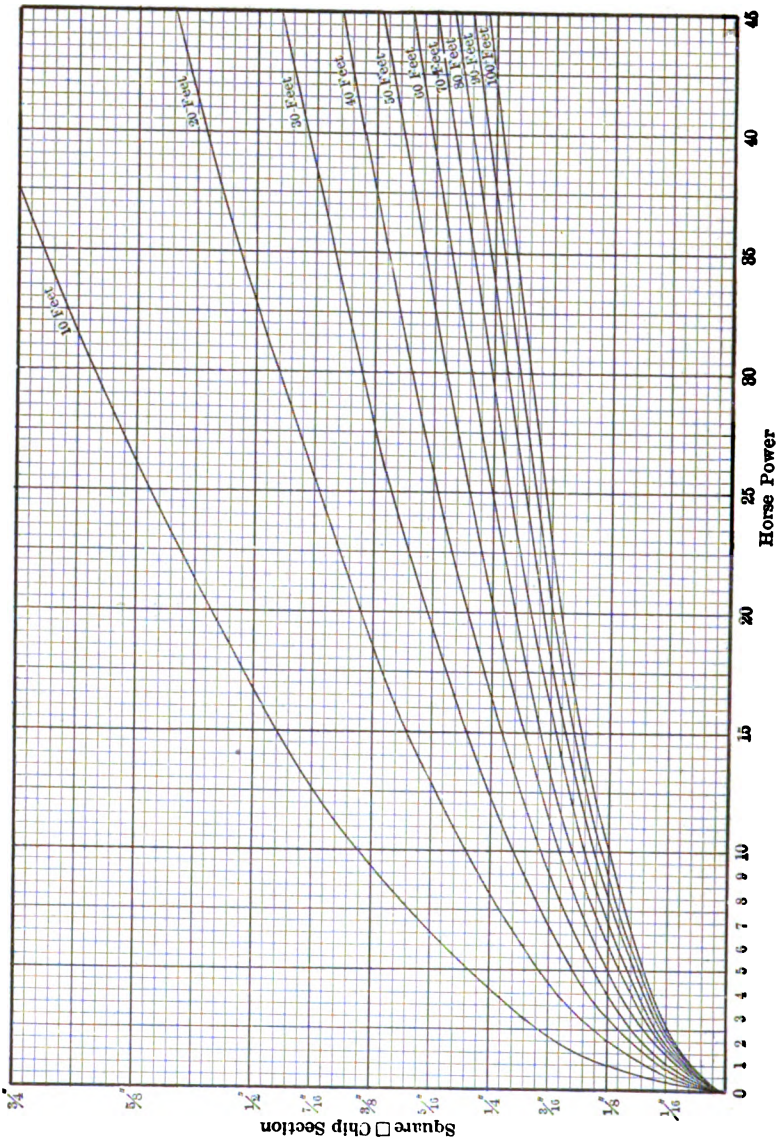

Fig. 2054b. — Wrought Iron.

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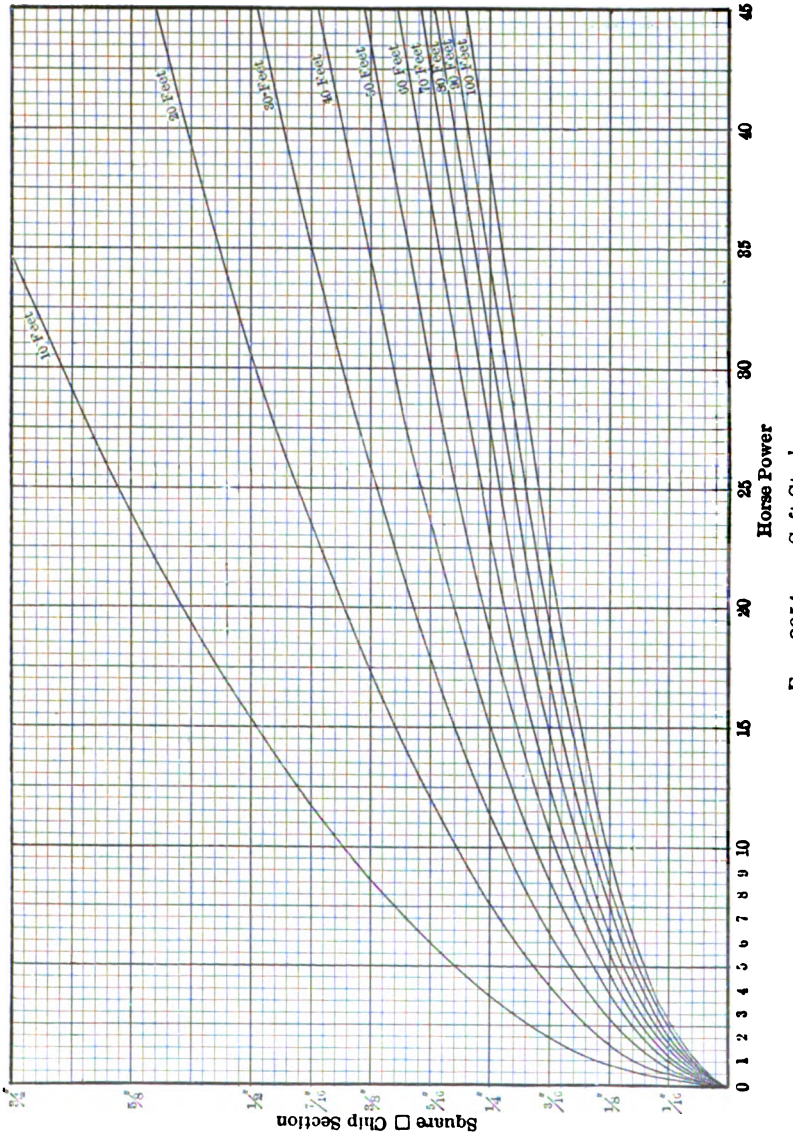

FIG. 2054c. — Soft Steel.

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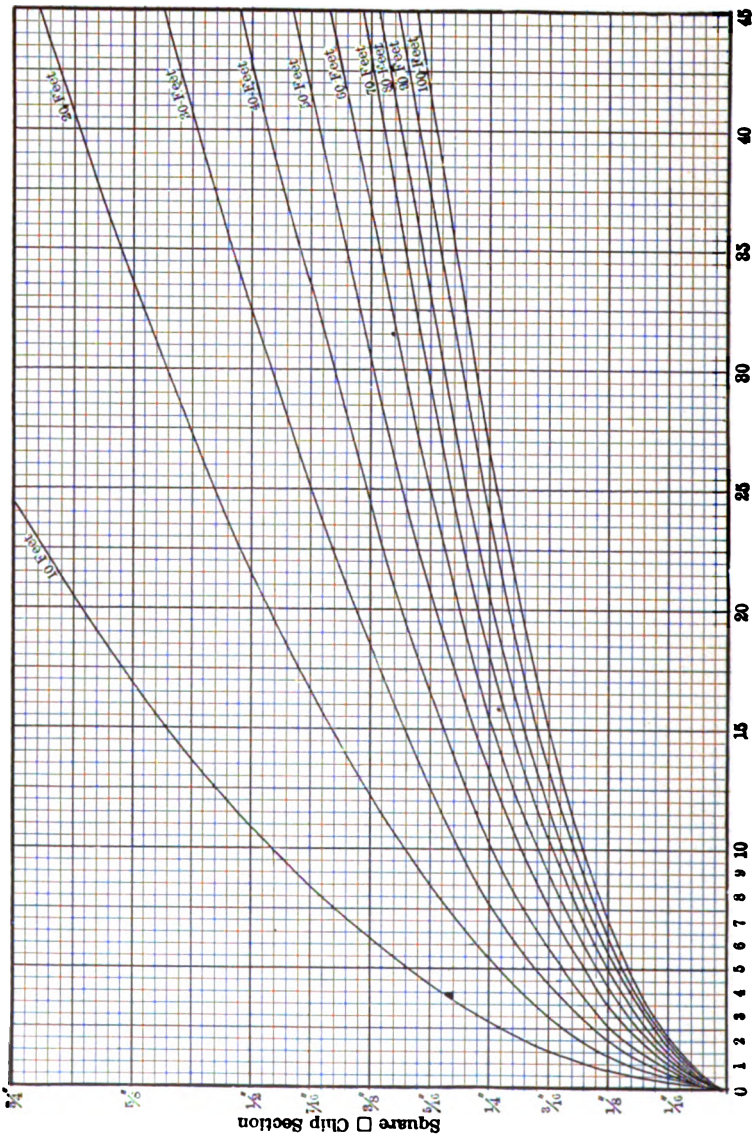

FIG. 2054d. — Cast Iron.

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HORSE-POWER REQUIRED AND WEIGHT OF CHIPS AT THE VARIOUS SPEEDS

Size of Chip	10 FEET		20 FEET		30 FEET		40 FEET		50 FEET		60 FEET		80 FEET		100 FEET	
	H. P.	Wgt.	H. P.	Wgt.	H. P.	Wgt.	H. P.	Wgt.	H. P.	Wgt	H. P.	Wgt.	H. P.	Wgt	H. P.	Wgt.
1/16" Sq.	.32	.13	.64	.26	.96	.39	1.3	.52	1.6	.65	1.9	.78	2.6	1.	3.2	1.3
1/8" Sq.	1.3	.53	2.6	1.1	3.9	1.6	5.2	2.1	6.5	2.7	7.8	3.2	10.4	4.2	13.	5.3
3/16" Sq.	3.	1.2	6.	2.4	9.	3.6	12.	4.8	15.	6.	18.	7.2	24.	9.6	30.	12.
1/4" Sq.	5.3	2.1	10.6	4.3	15.9	6.4	21.2	8.4	26.5	10.5	31.8	12.6	42.4	16.8	53.	21.3
5/16" Sq.	8.3	3.3	16.6	6.6	24.9	10.	33.2	13.2	41.5	16.5	49.8	19.8	66.4	26.4	83.	33.2
3/8" Sq.	12.	4.	24.	9.6	36.	14.3	48.	18.8	60.	23 5	72.	28.2	96.	37.6	120.	47.8
1/2" Sq.	16.2	6.5	32.4	13.	48.6	19.5	64.8	26.	81.	32 5	97.2	39.	129.6	52.	162.	65.1
5/8" Sq.	21.2	8.5	42.4	17.	63.6	25.5	84.8	34.	106.	42.5	127.2	51.	169.6	68.	212.	85.

FIG. 2054*aa*. HARD STEEL.

1/16" Sq.	.25	.13	.5	.26	.75	.39	1.	.52	1.3	.65	1.5	.78	2.	1.	2.5	1.3
1/8" Sq.	1.	.52	2.	1.	3.	1.6	4.	2.1	5.	2.6	6.	31.2	8.	4.2	10.	5.2
3/16" Sq.	2.3	1.1	4.6	2.2	6.9	3.3	9.2	4.4	11.5	5.5	13.8	6.6	18.4	8.8	23.	11.7
1/4" Sq.	4.2	2.1	8.4	4.2	12.6	6.	16.8	8.3	21.	10.4	25.2	12 6	33.6	16.6	42.	20.8
5/16" Sq.	6.5	3.3	13.	6.4	19.5	9.6	26.	12.8	32.5	16.	39.	19.5	52.	26.	65.	32.5
3/8" Sq.	9.4	4.7	18.8	9.4	28.2	14.1	37.6	18.8	47.	23.5	56 4	28.2	75.2	37.6	94.	47.
1/2" Sq.	12.8	6.4	25.6	12.8	38.4	19.2	51.2	25.6	64.	32.	73 8	38 4	102 4	51.2	128.	64.
5/8" Sq.	16.6	8.3	33.2	16.6	49.8	24.9	66.4	33.2	83.	41.5	99.6	49.8	132.8	66.4	166.	83.

FIG. 2054*bb*. WROUGHT IRON.

1/16" Sq.	.23	.13	.46	.26	.69	.39	.72	.52	1.15	.65	1.38	.78	1.8	1.6	2.3	1.3
1/8" Sq.	.95	.53	1.9	1.1	2.9	1.6	3.8	2.1	4.	2.7	5.7	3 2	7.6	4.2	9.5	5.3
3/16" Sq.	2.2	1.2	4.3	2.4	6.5	3.6	8.5	4.8	10.8	6.	12.9	7.2	17.3	9.6	21.6	12.
1/4" Sq.	3.8	2.1	7.6	4.3	11.4	6.4	15.2	8.5	19.	10.6	22.8	12.	30.	17.	38.	21.
5/16" Sq.	6.	3.3	12.	6.6	18.	10.	24.	13.3	30.	16.6	36.	19.9	48.	26 5	60.	33.
3/8" Sq.	8.6	4.	17.2	9.6	25.8	14.3	34.4	19.1	43.	23.9	51.6	28.6	68.8	38.2	86.	47.8
1/2" Sq.	11.7	6.5	23.4	13.	35.1	19.5	46.8	26.	58.5	32.5	70.2	39.	93.6	52.	117.	65.
5/8" Sq.	15.3	8.5	30.6	17.	45.9	24.5	61.2	34.	76.5	42.5	91.8	51.	122.4	68.	153.	85.

FIG. 2054*cc*. SOFT STEEL.

1/16" Sq.	.17	.12	.34	.24	.54	.36	.68	.48	.85	.60	1.	.72	1.3	.96	1.7	1.2
1/8" Sq.	.69	.49	1.3	.98	1.9	1.4	2.7	1.9	3.4	2.4	4.1	2 9	5.5	3.9	6.9	4.9
3/16" Sq.	1.5	1.1	3.2	.2	4.5	3.3	6.	4.4	7.5	5.5	9.	6.6	12.	8.8	15.	11.
1/4" Sq.	2.6	1.9	5.23	.8	7.8	5.7	10.4	7.6	13.	9.5	15.6	11.4	20.8	15.2	26.	19.
5/16" Sq.	4.2	3.	8.4	6.	12.6	9.	16.8	12.	21.	15.	25.2	18.	33.6	24.	42.	30.
3/8" Sq.	6.2	4.4	12.4	8.8	18.6	13.2	24.8	17.6	31.	22.	37.2	26.4	49.6	35.2	62.	44.
1/2" Sq.	8.4	6.	16.8	12.	25.2	18.	33.6	24.	42.	30.	50.4	36.	67.2	48.	84.	60.
5/8" Sq.	10.9	7.8	21.8	15.6	32.7	23.4	43.6	31.2	54.5	39.	65.4	46.8	87.2	62.4	109.	78.

FIG. 2054*dd*. CAST IRON.

2055. Horse-powers of the Motor Equipments for Various Machine Tools. The data from which the curves on this chart (Fig. 2055) were derived have been gathered from numerous sources and actual installations that have been found satisfactory. The values plotted are ample for the heavy cuts of general practice, and are slightly higher than those given by Mr. Pomeroy—General Electric Review, 1908. The several charts which he

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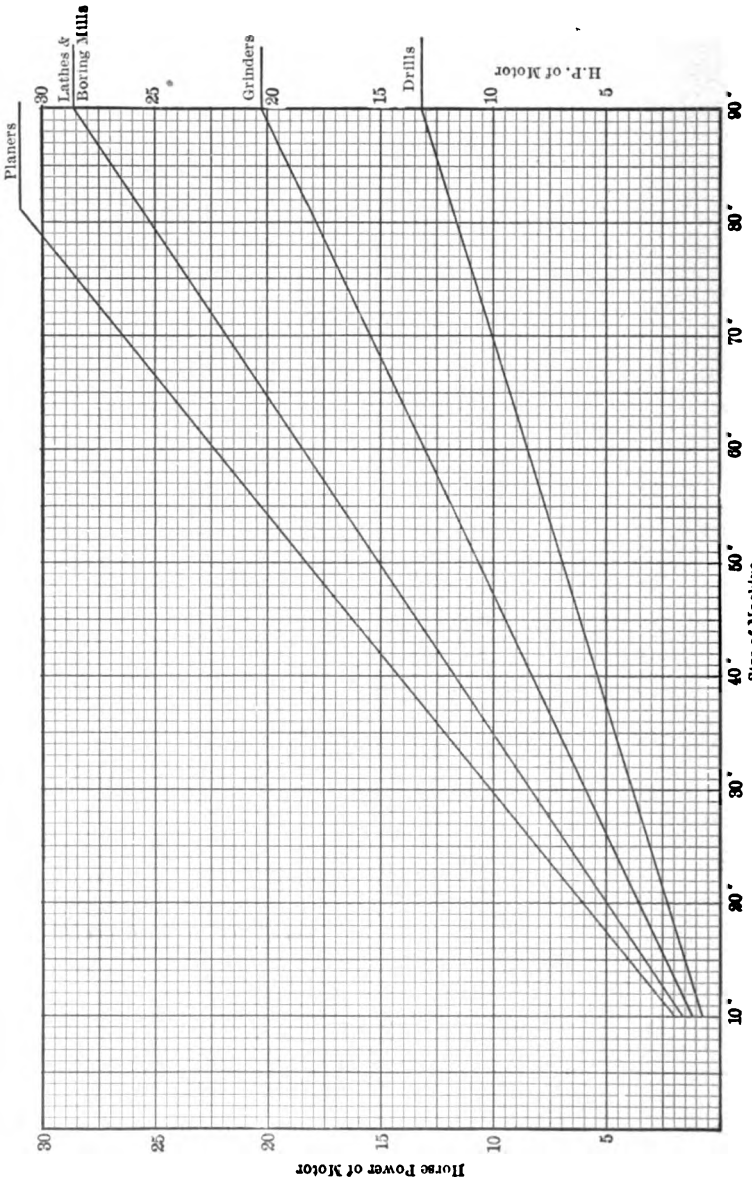

FIG. 2055. — Horse-power of the Motor Equipment for Various Machine Tools.

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submits, contain the plottings collected from a wide range of installations in railroad shops. The diagram is simple and requires no explanation. However, if it is desired to know the size of motor required for a 52″ boring mill, follow the curve marked lathes and boring mills to its intersection with the ordinate marked 52; follow the abscissa horizontally to the left and read the horse-power required, 15. The results obtained by this chart are, of course, general; motors are not built in sizes varying by ½ horse-power or even 3 horse-power and so the commercial motor nearest the size obtained is the one to select for ordinary work.

It should be noted that when heavy chips with high-speed steel are contemplated that the horse-power of the motor should be governed by the power necessary to remove the chip desired. Data for these calculations will be found in Sec. 2054, entitled "Horse-power Required to Remove Chips of a Given Area."

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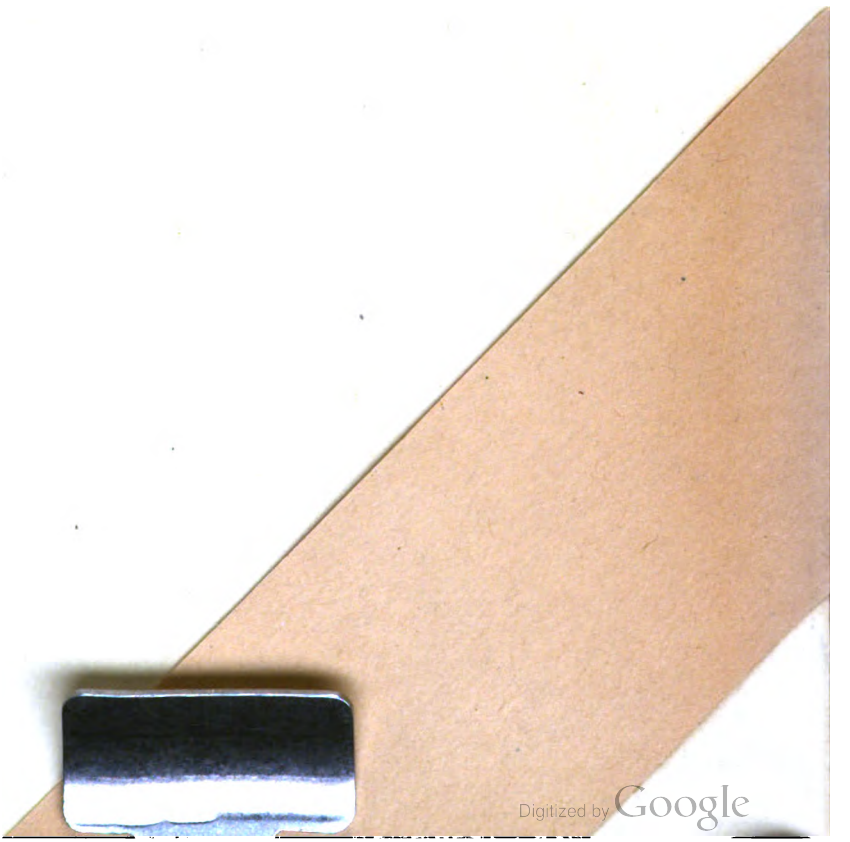

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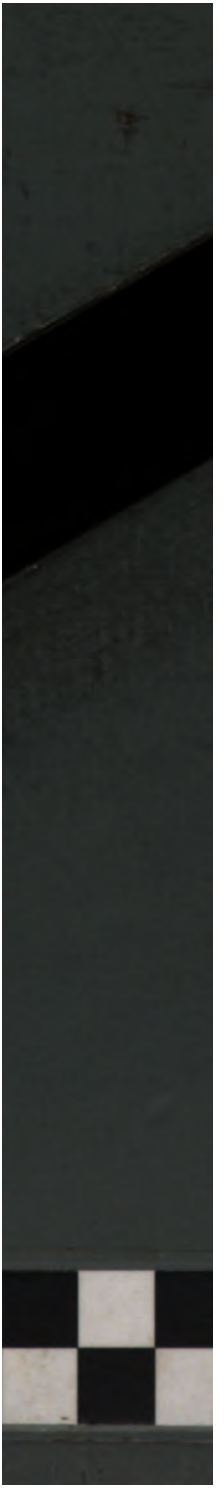

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